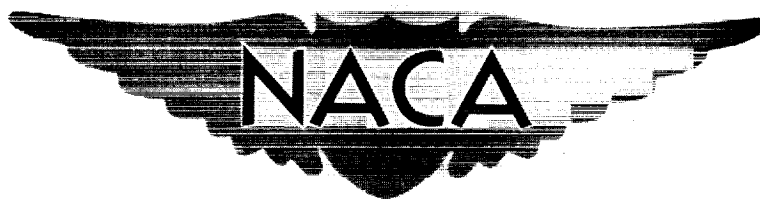


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RESEARCH MEMORANDUM

INVESTIGATION OF AERODYNAMIC AND ICING CHARACTERISTICS
OF A FLUSH ALTERNATE-INLET INDUCTION-SYSTEM

AIR SCOOP

By James P. Lewis

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

**NATIONAL ADVISORY COMMITTEE
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WASHINGTON

July 24, 1953

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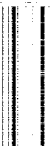
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUMINVESTIGATION OF AERODYNAMIC AND ICING CHARACTERISTICS OF A
FLUSH ALTERNATE-INLET INDUCTION-SYSTEM AIR SCOOP

By James P. Lewis

SUMMARY

An investigation has been made in the NACA Lewis icing research tunnel to determine the aerodynamic and icing characteristics of a full-scale induction-system air-scoop assembly incorporating a flush alternate inlet. The flush inlet was located immediately downstream of the offset ram inlet and included a 180° reversal and a 90° elbow in the ducting between inlet and carburetor top deck. The model also had a preheat-air inlet. The investigation was made over a range of mass-air-flow ratios of 0 to 0.8, angles of attack of 0° and 4°, airspeeds of 150 to 270 miles per hour, air temperatures of 0° and 25° F, various liquid-water contents, and droplet sizes.

The ram inlet gave good pressure recovery in both clear air and icing but rapid blockage of the top-deck screen occurred during icing. The flush alternate inlet had poor pressure recovery in both clear air and icing. The greatest decreases in the alternate-inlet pressure recovery were obtained at icing conditions of low air temperature and high liquid-water content. No serious screen icing was observed with the alternate inlet. Pressure and temperature distributions on the carburetor top deck were determined using the preheat-air supply with the preheat- and alternate-inlet doors in various positions. No screen icing occurred when the preheat-air system was operated in combination with alternate-inlet air flow.

INTRODUCTION

The problem of suitably protecting a reciprocating-engine induction system from icing arose in the design of a large transport airplane. Throttling and fuel-evaporation icing may be satisfactorily eliminated by the methods outlined in reference 1. The induction-system icing problem can therefore be confined to impact icing of the air scoop, the ducts, the carburetor screen, and the air-metering parts. Impact icing may be effectively prevented by heating the charge-air supply or by preventing free water from entering the induction system.

Nearly all aircraft induction systems employ some type of alternate inlet to provide a sheltered- or heated-air supply. In the aforementioned design problem the heated air supply, although heating the inlet air sufficiently to prevent icing, did not provide the pressure recovery required for the critical engine operation conditions. An alternate inlet based on the principle of inertia separation and careful aerodynamic design can effectively eliminate impact icing of the induction system and at the same time preserve the required ram-recovery performance. An example of such a system using an under-cowling scoop is reported in reference 2. Another type of inlet employing the inertia-separation principle is the flush or recessed inlet. Such inlets have been used to obtain ice-free fuel-cell vents (ref. 3).

In the present design, a flush alternate inlet located immediately downstream of the primary offset ram inlet was used. The duct from the alternate inlet included a 180° reversal and a 90° elbow before leading to the carburetor; thus, a region of secondary-inertia separation was provided (figs. 1 and 2). In order to evaluate the performance of such an induction system in icing conditions, an investigation of a full-scale model was conducted in the icing research tunnel at the NACA Lewis laboratory. The objectives of the investigation were to determine the icing characteristics of the system, the aerodynamic performance of the alternate inlet, and the performance of combined operation of the ram-, alternate-, and preheat-air supply systems. Tests were conducted over a range of airspeeds from 150 to 270 miles per hour, angles of attack of 0° and 4°, tunnel-air temperatures of 0° and 25° F, and mass-air flow ratios of 0 to 0.8 on various system configurations for both clear-air and icing conditions.

SYMBOLS

The following symbols are used in this report:

H	total pressure referenced to test chamber, in. water
l/L	ratio of local distance to total distance across inlet or carburetor top deck (see fig. 4).
M	mass air flow, lb/sec
p	static pressure referenced to test chamber, in. water
q	dynamic pressure, in. water
t	air total temperature, °F
η	pressure recovery, $\left[1 - \left(\frac{H_0 - H_c}{q_0} \right) \right] 100$, percent

Subscripts:

- 0 free-stream conditions
- a alternate-inlet system
- c carburetor top deck
- p preheat
- r ram-inlet system

APPARATUS AND INSTRUMENTATION

The model used in the icing tunnel investigation consisted of the offset ram-air scoop and the flush alternate inlet mounted on a full-scale section of the top of an engine nacelle. A photograph showing the model mounted in the test section of the icing tunnel is given in figure 1. The model was designed and built by an aircraft manufacturer. Because of space limitations, the alternate-inlet design differed from that recommended by the NACA Ames laboratory for flush inlets, and excessive side wall-divergence and ramp angles resulted. A schematic diagram of the test setup is shown in figure 2. Inlet air from ram, alternate, and preheat inlets is ducted to the carburetor top-deck section and thence through the tunnel floor to an exhaustor which provides the required charge air flow. The two air-flow-control doors, which are operated manually and independently, are shown in the closed position. The preheat door when closed blocks the preheat-air supply and allows full ram-air flow to the carburetor; when fully open, it blocks off the ram-air flow and permits full preheat air to enter the carburetor. The alternate door when closed blocks the alternate-air flow and permits either ram air or preheat air to enter the carburetor. When fully open, the alternate door blocks both the preheat and ram air; then, only alternate air flows to the carburetor. Both doors could be set at intermediate positions.

In this investigation, preheat air at the required temperature and flow rate was obtained from a compressed-air supply and heat exchanger. Removable panels permitted access to the alternate-duct elbow and to the removable carburetor top-deck section to permit observation of icing. Details of the geometry of the alternate-inlet are given in figure 3.

The pressure recovery at the carburetor top deck was determined from measurements of the top-deck total pressure. Electrically heated total-pressure tubes were installed at the carburetor top deck for all tests. The ends of the tubes projected approximately $3/4$ inch upstream of the carburetor screen. For the clear air runs, unheated total-pressure tubes were installed between the lip and the ramp of the alternate inlet. Four thermocouples were located across the carburetor top deck to obtain the temperature distribution during tests with preheat air. A static-pressure tap was located in the preheat-air plenum. The

location of the total-pressure tubes and thermocouples is given in figure 4. All air-flow measurements were made by means of thin-plate orifices. Thermocouples were also used to measure the preheat-air and exhaust-air temperatures.

PROCEDURES

Aerodynamic Tests

The carburetor top-deck pressure recovery was determined for both the ram and alternate inlets for clear air over a range of mass-air-flow ratios at angles of attack of 0° and 4° . Pressures at the alternate inlet were also obtained in clear air with varying mass flows through the alternate inlet for angles of attack of 0° and 4° . All these tests were made at airspeeds of approximately 150, 200, and 270 miles per hour, mass-flow rates of 0 to 3.55 pounds per second, and a tunnel-air total temperature of 25° F. Flow studies with wool tufts were made over the forward nacelle area and the alternate-inlet ramp.

Icing Tests

Both the ram- and alternate-inlet systems were tested in icing conditions to determine the type of icing on the external surfaces and the inner ducting, the degree of blockage of the carburetor screen, and the effects of icing on the pressure recovery. Tests were made at various combinations of liquid-water content and median-droplet diameter for airspeeds of 150 to 180 miles per hour, tunnel-air total temperature of 0° and 25° F, angles of attack of 0° and 4° , and mass-air-flow ratios of 0.35 to 0.8. The combinations of liquid-water content and droplet size used in the investigation were chosen to give the maximum rate of impingement. The values chosen are based upon a probability of being exceeded of less than 1 in 100 as given in the statistical analysis of icing conditions in reference 4. The droplet diameter hereinafter referred to is the median diameter; the size distribution of water droplets in the icing tunnel corresponds to approximately a D distribution as defined in reference 5.

The procedure followed in the icing tests was as follows: After the system was stabilized at the desired tunnel airspeed and temperature conditions and the desired flow rate through the model, an initial clear-air reading including the top-deck pressures was made. The icing cloud was then turned on, all pertinent data were recorded at various time intervals, and photographs of the ice on the inlets were taken during the icing period. Efforts were made to maintain constant mass air flow through the model within the limit of performance of the exhaust fan by

opening or closing the control valve in the exhaust line. At the end of each test, photographs were taken of the ice on the inlets, the interior ducting, and the carburetor screen. The length of each icing test was determined from considerations of the extent and severity of natural icing conditions and the rate of change of the pressure recovery and mass-flow blockage through the model.

Preheat-Air Tests

Three groups of tests were made using the preheat-air supply. The first group of tests was made in clear air with the preheat door fully open and the alternate door closed (no ram- or alternate-inlet-air flow). Although it was not necessary to operate the tunnel for these tests, an airspeed of 200 miles per hour and a tunnel-air total temperature of 25° F were used to simulate possible flow leakage and heat conduction in the model. The temperatures and pressures at the top deck were measured over a range of mass air flows of 0.75 to 3.5 pounds per second at preheat-inlet-air temperatures of approximately 135° and 210° F.

In the second group of preheat tests, made at an airspeed of 150 miles per hour and a tunnel-air total temperature of 25° F, the effects of various door positions on the pressure recovery and the air-temperature distribution were determined in clear air. Tests were made at constant values of preheat and carburetor mass air flow with both the alternate and the preheat doors set at various percentages of full travel to give mixtures of preheat-, ram-, and alternate-inlet air. The top-deck temperature and pressure distributions were recorded.

Both clear air and icing conditions were used in the third series of preheat tests; the preheat door was fully open (no ram), and the alternate door was set at various positions. The preheat-inlet mass air flow was held constant, and the alternate-inlet mass air flow was increased by manipulating the alternate door. The tests were made at an airspeed of 150 miles per hour, a tunnel-air total temperature of 25° F, an angle of attack of 0°, a liquid-water content of 0.6 gram per cubic meter, a droplet diameter of 10 microns, and an average preheat-air inlet temperature of 212° F. Measurements were made of the temperature and pressure distribution across the carburetor top deck for both clear air and icing conditions.

RESULTS AND DISCUSSION

Ram-Inlet Tests

Clear air. - The variation of the average top-deck pressure recovery η_{av} with the inlet mass-air-flow ratio in clear air is presented

in figure 5(a). These results were obtained at an airspeed of approximately 200 miles per hour, a tunnel-air total temperature of 25° F, and angles of attack of 0° and 4° . Excellent ram recovery was obtained over the entire range of mass-air-flow ratios tested, the performance at an angle of attack of 4° being slightly better than at 0° .

Icing. - The performance of the ram-inlet system in icing conditions is shown by the results of figures 5(b) and 5(c). Although only limited data were obtained, the effect of icing on the top-deck average pressure recovery (fig. 5(b)) was almost negligible, being approximately the same for a three-fold increase in liquid-water content. The pressure distribution across the top deck remained essentially uniform and the pressure-recovery measurements indicate the effect of inlet and duct-wall icing rather than screen icing because the pressure tubes extended above the top-deck screen. The much greater effect of the mass flow is shown in figure 5(c). The carburetor screen was almost completely blocked by ice, which caused reductions in the mass flow of approximately 60 to 90 percent. Very poor pressure recovery would, of course, be obtained downstream of the blocked screen. The immediate decrease in the mass flow shown in figure 5(c) resulted from the limited capacity of the exhaust blower which did not allow a constant flow rate to be maintained.

Photographs of ice on the ram inlet and the carburetor screen at the end of the icing periods are shown in figure 6. At the higher liquid-water-content condition (fig. 6(a)), a rough-glaze-ice formation which built outward from the inlet was obtained on the ram-inlet lips. Little or no ice was observed inside the ram duct. Downstream of the ram inlet, almost the entire scoop including the alternate-inlet ramp was covered by a frost-like formation. This frost icing is believed to result from a combination of super saturation in the tunnel and turbulent deposit of small drops caused by the presence of rough ice formations on the ram-inlet lips. A small semiglaze formation was obtained on the alternate-inlet lip. The formations on the alternate inlet were symmetrical. A heavy glaze ice almost completely blocked the screen; the heated total-pressure tubes maintained small areas ice-free. The screen icing was somewhat heavier at the rear than at the front of the top deck. At the low liquid-water condition (fig. 6(b)), the ram-inlet-lip ice consisted of a dense rime formation which built toward the center of the inlet in contrast to that at the higher water-content condition. Icing of the alternate inlet was very similar to that previously observed. A very slight icing of the ram duct and elbow was obtained. Heavy screen icing again occurred, with more ice deposited at the rear than at the front of the top deck. The difference between the two types of ice formed at the same air temperature is attributed to the greater rate of collection that exists when the liquid-water content is high and the droplet diameters are large; the greater heat of fusion obtained under these conditions caused the rough glaze formation.

The effect of icing on the top-deck pressure distribution is shown in figure 7, which presents a comparison of typical distributions dry and after 8 minutes of icing with the ram inlet in operation. The most significant result is the decrease in pressure recovery at the front of the top deck. The pressures elsewhere over the top deck were fairly uniform and showed only a slight decrease despite the presence of large rough ice formations on the inlet lips.

Alternate-Inlet Tests

Clear air. - The average top-deck pressure recovery for the alternate inlet in clear air is presented in figure 8 as a function of the inlet mass-flow ratio. In contrast to the excellent recovery characteristics of the ram inlet, the alternate inlet gave negative recovery over the whole range of mass-flow ratios with values as great as $1/3$ of the test-section dynamic pressure. The poor performance of the alternate inlet is attributed to the excessive divergence and ramp angles of the inlet design. The negative values of the pressure recovery result from the definition of recovery coefficient in terms of gage total pressures and stream dynamic pressures. The negative values of the pressure recovery indicate not a reverse air flow but a loss in energy which had to be supplied by the exhaustor. Considerable scatter of the data resulted and poorer recovery was obtained at the 4° angle of attack condition than at 0° . In an effort to determine the cause of this poor recovery, tuft studies were made over the entire alternate-inlet area. These studies indicated considerable flow instability and separation over the inlet ramp, particularly on the sides of the ramp and at the inlet lip. Total-pressure rakes were also installed at three lateral stations at the alternate-inlet lip. The results obtained from these rake measurements are presented in figures 9 and 10 for two angles of attack at various mass flows. The pressure surveys showed poor recovery at the inlet lip with considerable nonuniformity in the flow existing in both the horizontal and vertical planes. Only at the center of the inlet and at the higher mass flows, particularly at an angle of attack of 0° , was good recovery obtained. For this reason only the center area of the inlet should, in general, be used in evaluating the water-exclusion performance of the alternate inlet.

Icing. - The variation of the average top-deck pressure recovery with icing time for the alternate inlet, is shown in figure 11 for constant liquid-water content and droplet-size conditions at various mass-flow ratios and tunnel-air temperatures. The rates of change in recovery at the higher temperature were practically identical, and only a slightly greater rate of change was obtained at the low-temperature conditions. The poorer recovery obtained at the lower temperature probably resulted from the presence of frost on the alternate-inlet ramp and forebody. No icing of the carburetor screen was obtained at the higher temperature, while only a small deposit of rime ice was obtained on the screen after 45 minutes of icing at 0° F.

Views of ice formed on the alternate-inlet scoop under the conditions given in figure 11 are shown in figure 12. The formations obtained at a tunnel-air total temperature of 25° F are practically the same (figs. 12(a) and 12(b)). The relatively small formations on the ram-inlet lips are believed to have no significant effect on the performance of the alternate inlet. It should be noted that the ice formations on the ram inlet are uniform as compared with the asymmetric formations on the alternate-inlet lip. These asymmetric formations result from the nonuniform air flow at the alternate inlet. At the lower temperature (fig. 12(c)), the alternate-inlet and ram-inlet lips had formations similar to but slightly greater than those obtained at 25° F. In addition, the air scoop was covered with a fine frost-like formation.

The ice obtained after 45 minutes of icing at a temperature of 0° F is shown in figure 13. The external icing was similar to that of figure 12(c), but considerably greater. The frost formations also increased and indicate clearly the nature of the air flow at the alternate inlet. A considerable deposit of ice formed at the center of the elbow of the alternate duct. The rearward build-up of the ice nodules on the upper duct indicates a reverse air flow in this region. The screen icing resulted in very slight blocking except at the center in the region of the blank representing the carburetor altitude compensator.

The effect of more severe icing conditions on the pressure recovery is presented in figure 14. Increasing the liquid-water content and droplet size resulted in successively greater and more immediate changes in the pressure recovery, but an equilibrium value was attained in approximately 15 minutes in all cases. No screen icing and practically no duct icing were observed at these conditions; thus, improved water separation was obtained with the larger diameter droplets as compared with that obtained with the smaller droplets (figs. 11 to 13). At a liquid-water content of 1.5 grams per cubic meter in figure 14, the pressure recovery suddenly changed after the icing cloud was turned off. This effect is attributed to the fact that the exhaustor was turned off simultaneously with the icing cloud; thus, warm air was allowed to flow backward through the model into the tunnel. The warm air flow caused melting and loss of frost on the ramp and some of the ice on the alternate lip.

Photographs of the ice on the model at the end of the icing periods (corresponding to the results of fig. 14) are shown in figure 15. In contrast to the smooth rime formations obtained with the lower liquid-water content and the smaller-diameter droplets (figs. 12 and 13), the ram-inlet lips were covered with a rough glaze ice that built outward into the air stream. Again, a nonuniform ice formation on the alternate-inlet lip was obtained although not as marked as at the less severe icing conditions. The entire scoop, including the alternate ramp, was covered with the frost-like formation previously obtained only at the lower temperature.

The change in the top-deck pressure recovery with icing time at an angle of attack of 4° is shown in figure 16. The results are, in general, similar to those obtained at an angle of attack of 0° . The low-temperature conditions show the greatest sensitivity to icing; this is again attributed to the frost icing of the ramp and forebody. Photographs of the ice formations obtained at an angle of attack of 4° are shown in figures 17 and 18. The icing of the exterior of the model closely resembled that obtained at similar icing and mass-flow-ratio conditions at an angle of attack of 0° . At the higher temperature, slight amounts of screen icing were obtained with a considerable deposit of ice on the elbow of the alternate-inlet duct. The amount of ice obtained on the screen at the lower temperature was about the same as that obtained at an angle of attack of 0° with a 50-percent-longer icing period (fig. 13). Again, ice deposits occurred in the center of the elbow. The poorer pressure recovery and the greater amount of screen icing obtained at an angle of attack of 4° are believed to be partly caused by the lip ice formations building out into the air stream and giving a greater water scooping effect.

The ice formations obtained for all conditions on the alternate inlet and inducting were very unevenly distributed, either located to one side as on the alternate-inlet lip or concentrated in the center as on the ducting and the screen. The effect of icing on the local top-deck pressure-recovery distribution is shown in figure 19, which presents a comparison of typical distributions in clear air and after 30 minutes of icing with the alternate inlet in operation. No significant change in the pressure recovery distribution was found despite uneven icing of the inlet lip, the ducting, and the screen and considerable changes in both pressure recovery and mass flow.

Because of the poor recovery characteristics of the flush alternate inlet, it is difficult to anticipate the water-separation characteristics of such an inlet having good aerodynamic performance. For those areas of the present inlet where good local recoveries were obtained, the resultant local ice formations on the elbow and the screen were the largest obtained but still relatively small. No serious screen icing occurred at any time with the alternate inlet. The decrease in pressure recovery with icing is attributed primarily to the frost-like formations on the inlet ramp and to icing on the inlet lip. The relative effect of these ice formations was not specifically determined although loss of the ramp frost gave an increase in recovery, and the greatest effects on recovery were obtained at the low-temperature and high-water-content conditions which caused the greatest ramp frosting. The results of reference 3 also indicate the sensitivity of flush inlets to icing of the ramp and forebody.

Preheat-Air Tests

Preheat air only. - The temperature distribution across the top deck with no ram- or alternate-air flow for various preheat-air flows is shown in figure 20. In all cases, a very uniform temperature distribution was obtained over the range of preheat air flows and temperatures. At a constant preheat-air inlet temperature of 135°F and a tunnel-air temperature of 25°F , a variation of approximately 17°F in the average top-deck temperature resulted over the range of mass flows investigated.

Preheat air with modulated alternate-air flow. - The performance of the system with the preheat door full open and the alternate door at intermediate positions for both clear air and icing is shown in figure 21. These results were obtained with a constant preheat-air mass flow and temperature and an increase of the mass flow through the carburetor top deck with increasing alternate-door opening. The average top-deck temperature decreased with increasing alternate-door opening up to 40 percent; the temperature remained constant for alternate-door positions greater than 40 percent. The equivalent pressure recovery shown in figure 21(b) is negative for most door positions, and there is no significant improvement over that obtained with the alternate inlet alone. The preheat-plenum pressures varied between -0.75 and -0.06 of the stream dynamic pressure. In considering the temperature and pressure variations with opening of the alternate door, it should be remembered that opening of the alternate door progressively blocks the preheat-air flow. No significant changes in either the top-deck pressures or temperatures were obtained during a 15-minute icing period at a liquid-water content of 0.6 gram per cubic meter with median droplet diameters of 10 microns. No screen icing was obtained at any time.

The variation of the temperature across the top deck at various alternate-door positions is given in figure 22. At the 20-percent-open position, a temperature difference across the top deck of approximately 20°F was obtained as compared with an essentially uniform distribution at the 80-percent-open position. Again, no significant effect with icing was obtained. Since the minimum temperature is the important criterion in ice protection, the increased average temperature at the smaller door openings shown in figure 21(a) is only an apparent advantage. The alternate-door position, therefore, appears to be of relatively small importance as regards the critical top-deck temperature.

Photographs of the ice formed on the scoop and in the alternate-duct elbow after 15 minutes of icing with the alternate door 20, 40, and 80 percent full open and the preheat door fully open are shown in figure 23. The ice formations on the inlet lips are very similar to those obtained without preheat and with the alternate door full open at similar icing conditions (fig. 12). No significant difference in the

external scoop icing was obtained at the various door positions except for a shift of the ice formation from one side of the alternate-inlet lip to the other; this is believed to be caused by the unstable flow conditions existing at the alternate inlet. Icing of the alternate-duct elbow exhibited this same sidewise movement and also showed a progressively larger deposit of ice as the alternate-door opening and the air flow increased.

Modulation of preheat and alternate doors. - The effect on the top-deck pressure recovery and temperature for simultaneous opening of both the preheat and the alternate doors was obtained in clear air at an average preheat-air flow of 0.57 pound per second and a carburetor-air flow of 3.24 pounds per second. Varying the door positions in this manner is equivalent to starting with ram air only, changing to a combination of ram-, preheat-, and alternate-air flow, and ending with effectively alternate-air flow only. The variation of the average top-deck pressure recovery with door positions is given in figure 24. Both doors were opened the same amount for each condition. A linear relation over almost the entire door-position range was obtained. The distribution of the local pressure recovery over the top deck at three door positions is shown in figure 25. A very uneven distribution was obtained. The poorer recovery obtained at the front of the top deck appears to be caused by the preheat-air flow; the effect of the alternate-air flow does not appear to have any great detrimental effect for door positions of 40 percent open or less. The corresponding top-deck temperature distributions are shown in figure 26. Again, the presence of the preheat-air flow at the front of the top deck is noted, particularly at the 20-percent-open position. As in the case of the results of figure 22 (preheat door fully open, alternate door modulated), a uniform temperature distribution was obtained only at the wider-open door positions. The poor pressure recovery indicated for this case is of the same order of magnitude as that obtained with the preheat door fully open, figure 21(b). It would appear, therefore, that no great advantage is obtained by having the preheat door partially closed; in fact, a smaller temperature rise is obtained.

SUMMARY OF RESULTS

In an investigation of the aerodynamic and icing characteristics of a flush alternate-inlet induction-system air scoop, the following results were obtained:

1. The ram inlet gave good pressure recovery as measured upstream of the carburetor top-deck screen in both clear air and icing conditions. Rapid blockage of the carburetor top-deck screen was obtained during icing conditions.

2. The flush alternate inlet had poor pressure recovery characteristics over most of the inlet cross section for all conditions investigated in both clear air and icing conditions. No serious screen icing was obtained at the alternate inlet, even in those regions in which relatively good local pressure recovery occurred. The effects of icing on the pressure recovery are believed to result primarily from icing on the inlet lip and frost-like formations on the inlet ramp. The greatest effects of icing on the pressure recovery were obtained at conditions of low air temperature or high liquid-water content; at these conditions, the greatest ramp icing occurred. Variation of angle of attack from 0° to 4° gave no significant change in the alternate-inlet performance during icing.

3. A uniform temperature distribution across the top deck was obtained when only preheat air was used.

4. When preheat air was used with modulated alternate-inlet air flow, the pressure recovery showed no significant improvement over that obtained with alternate-air flow alone. A fairly uniform temperature distribution at the top deck was obtained. Icing had no effect on the top-deck pressure recovery and temperature, and no screen icing resulted.

5. Opening both alternate-air and preheat-air doors simultaneously provided a combination of ram-, preheat-, and alternate-air flow that gave fairly good pressure recovery, but poor top-deck temperature distribution resulted when these doors were not wide open. A good temperature distribution was obtained at the expense of poor pressure recovery when the doors were wide open.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, April 9, 1953

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Figure 1. - Installation of alternate-inlet air-scoop model in icing tunnel.

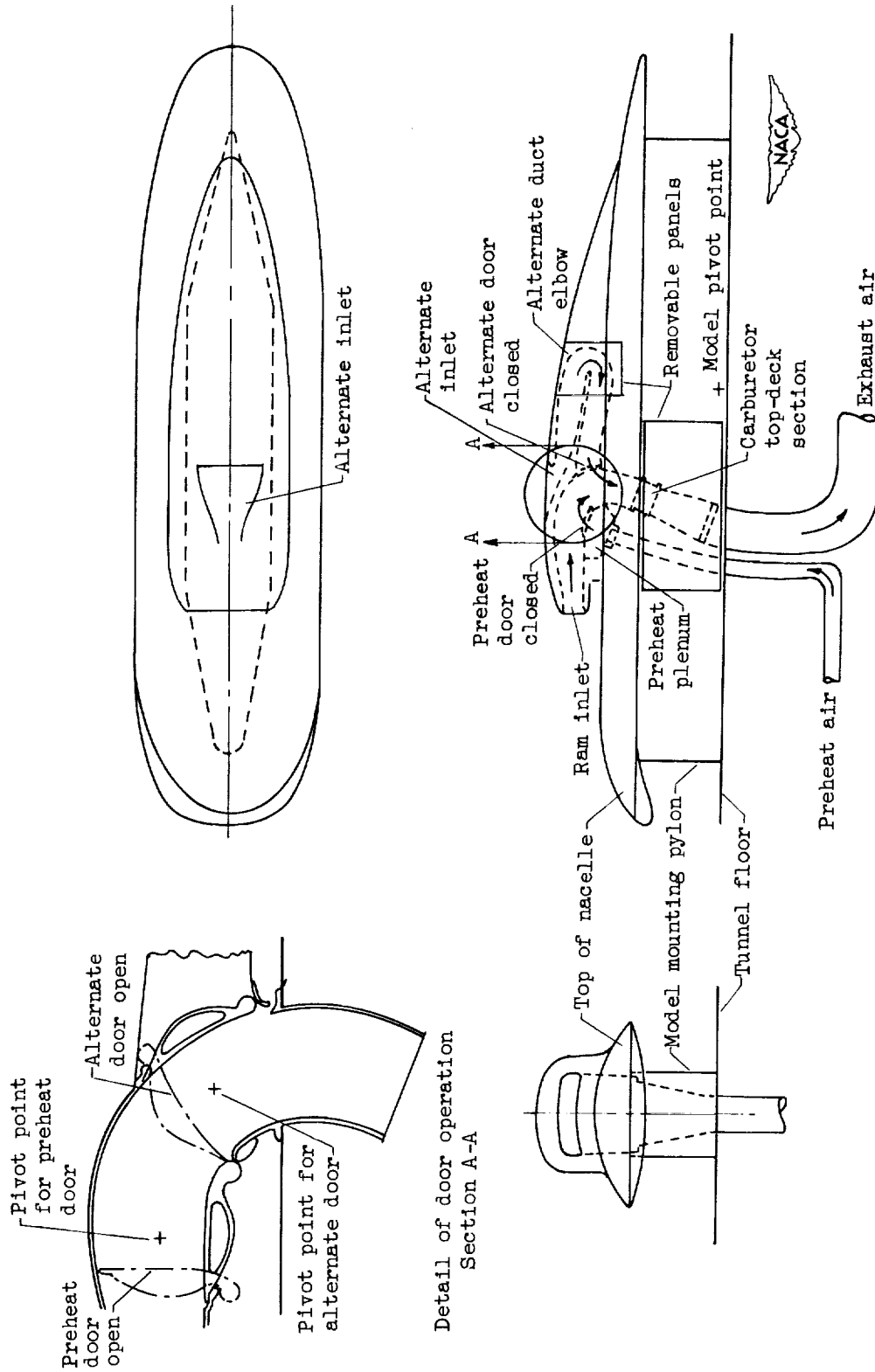


Figure 2. - Sketch of alternate-inlet air-scoop model installation in icing tunnel.

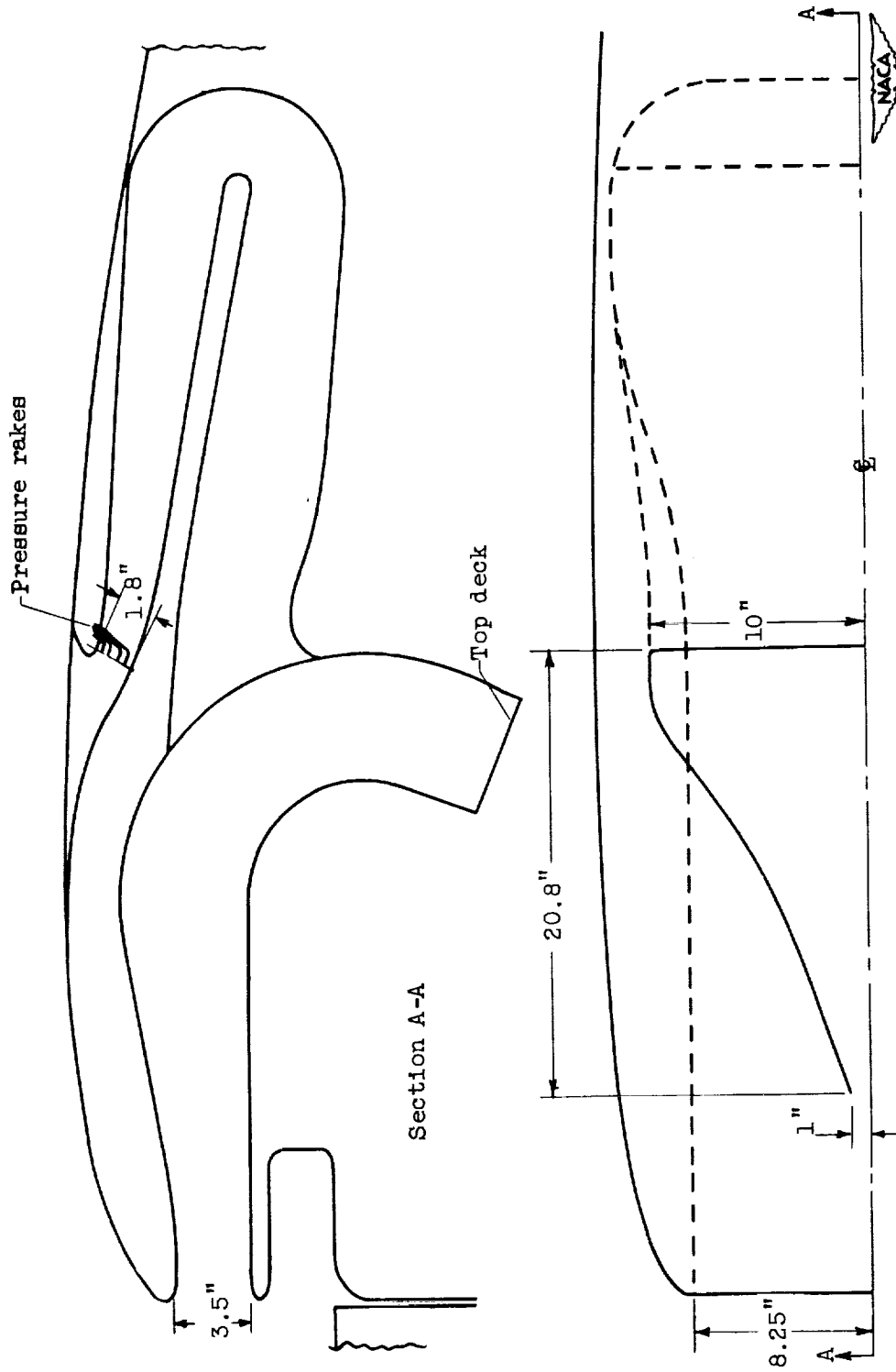
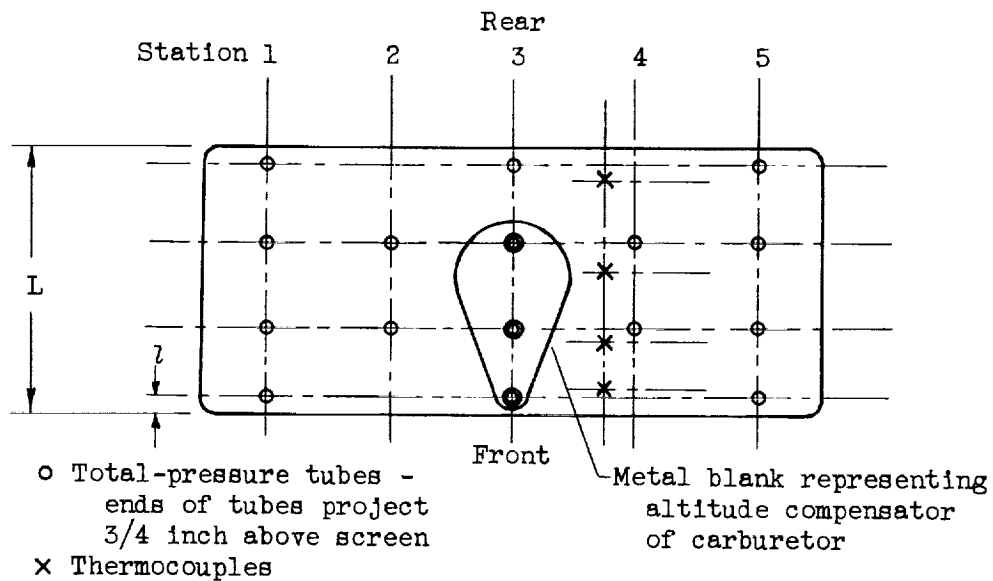


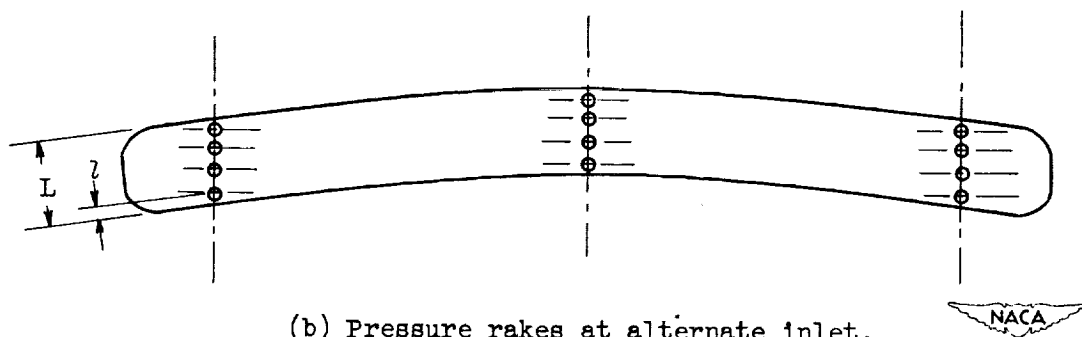
Figure 3. - Geometry of air-scoop inlets and ducting. Ram-inlet area, 57 square inches; alternate-inlet area, 36 square inches. (1/8 scale.)

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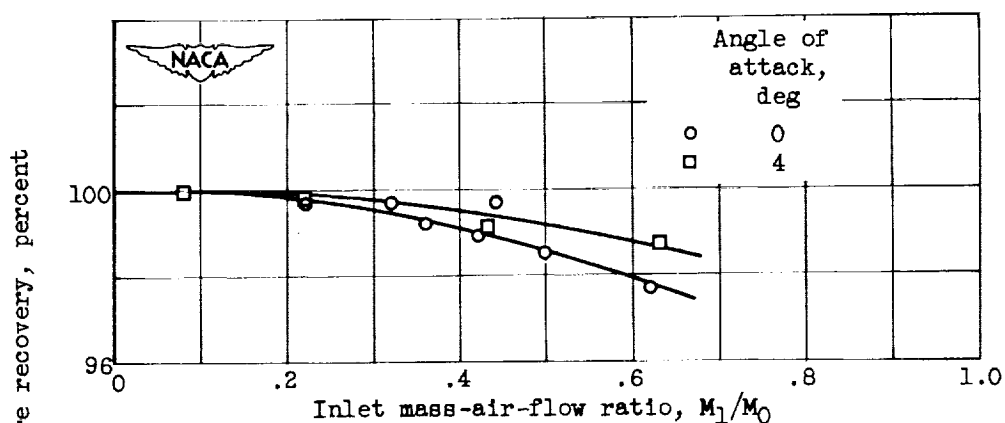


(a) Instrumentation at top-deck station.

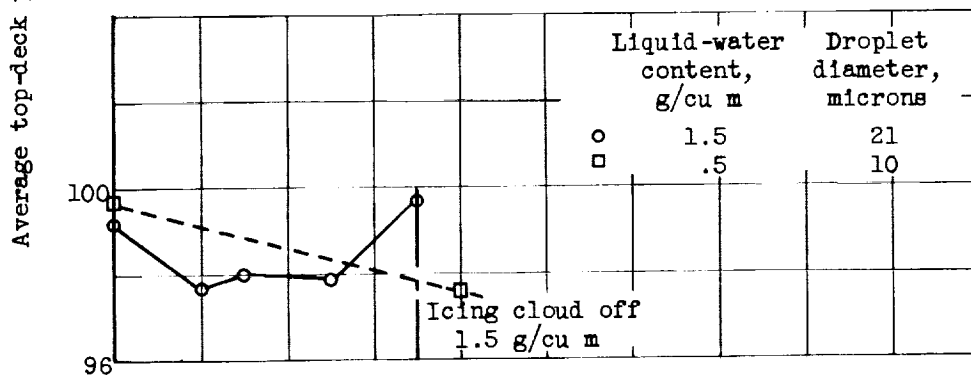


(b) Pressure rakes at alternate inlet.

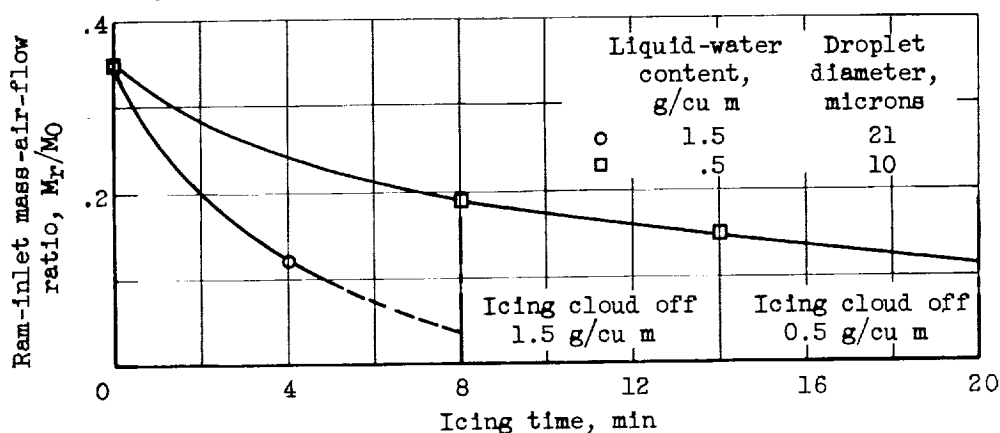
Figure 4. - Sketches showing instrumentation of alternate air-scoop model viewed in downstream direction.



(a) Average top-deck pressure recovery in clear air. Airspeed, 200 miles per hour; tunnel-air total temperature, 25° F.



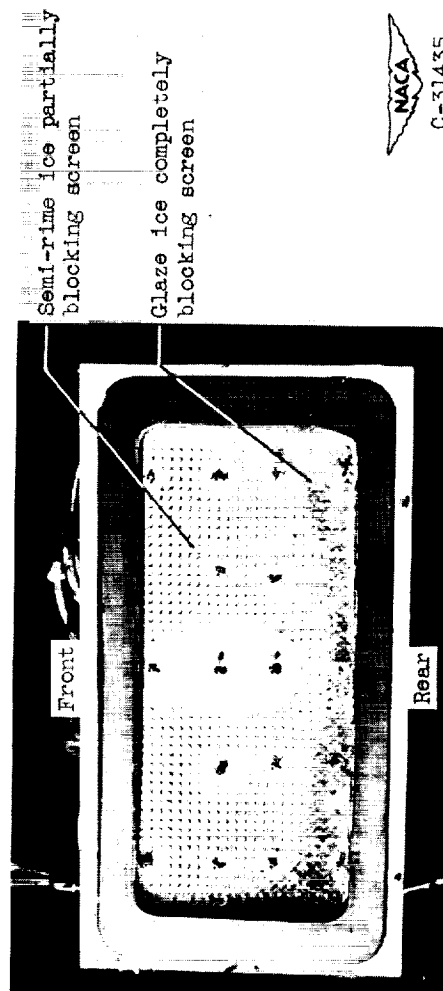
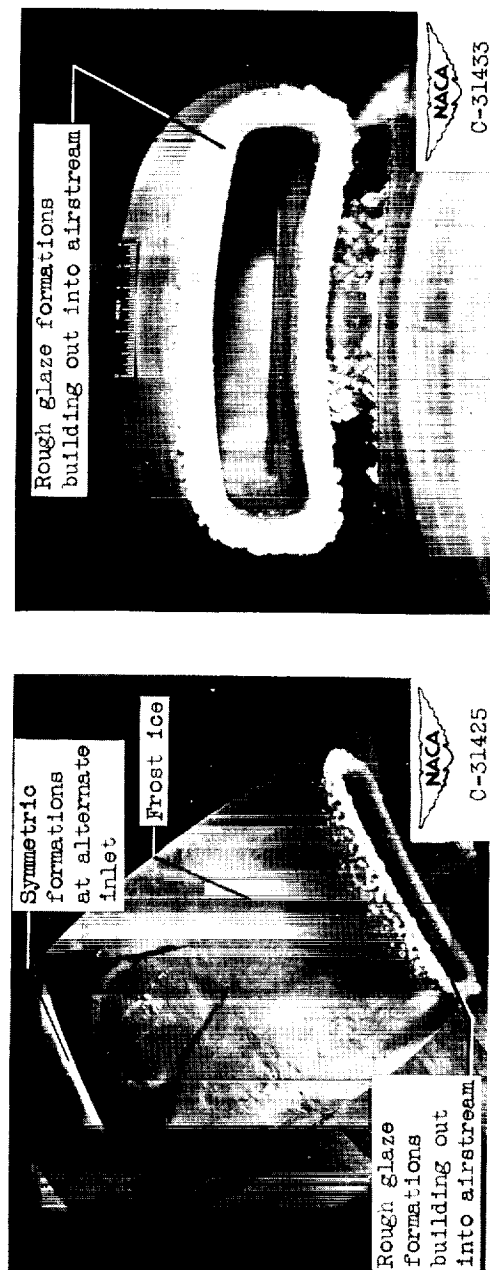
(b) Average top-deck pressure recovery in icing. Airspeed, 180 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°; initial mass-air-flow ratio, 0.35.



(c) Variation of mass-flow ratio in icing. Airspeed, 180 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°.

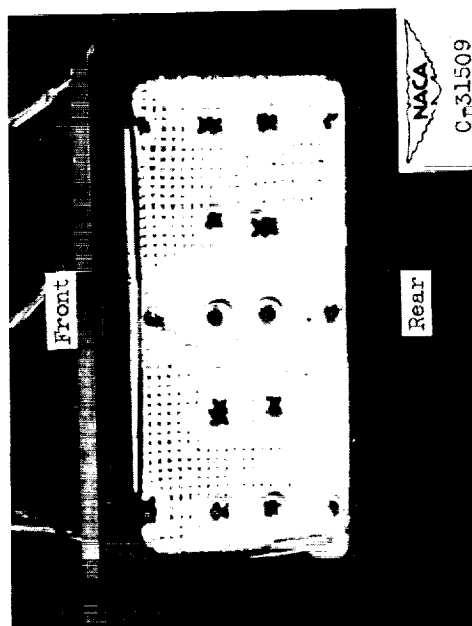
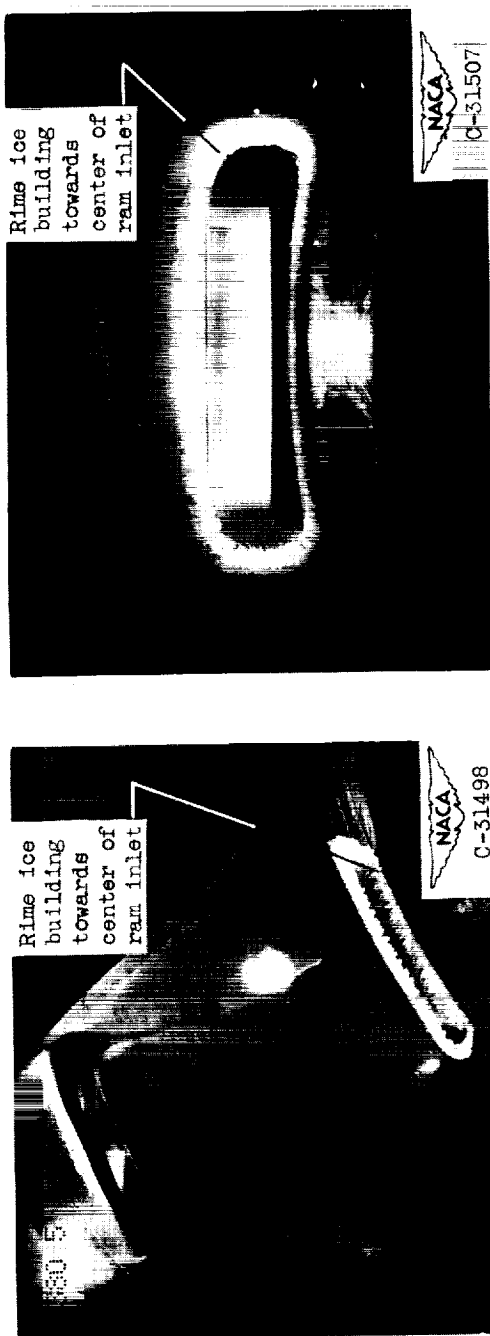
Figure 5. - Performance of ram-inlet system in clear air and in icing conditions.

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(a) Ice formed after 8 minutes. Liquid-water content, 1.5 grams per cubic meter; droplet diameter, 21 microns.

Figure 6. - Ice formed on ram inlet and carburetor screen at two icing conditions. Airspeed, 180 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°; initial mass-flow ratio, 0.35.



(b) Ice formed after 20 minutes. Liquid-water content, 0.5 gram per cubic meter; droplet diameter, 10 microns.

Figure 6. - Concluded. Ice formed on ram inlet and carburetor screen at two icing conditions. Airspeed, 180 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°; initial mass-flow ratio, 0.35.

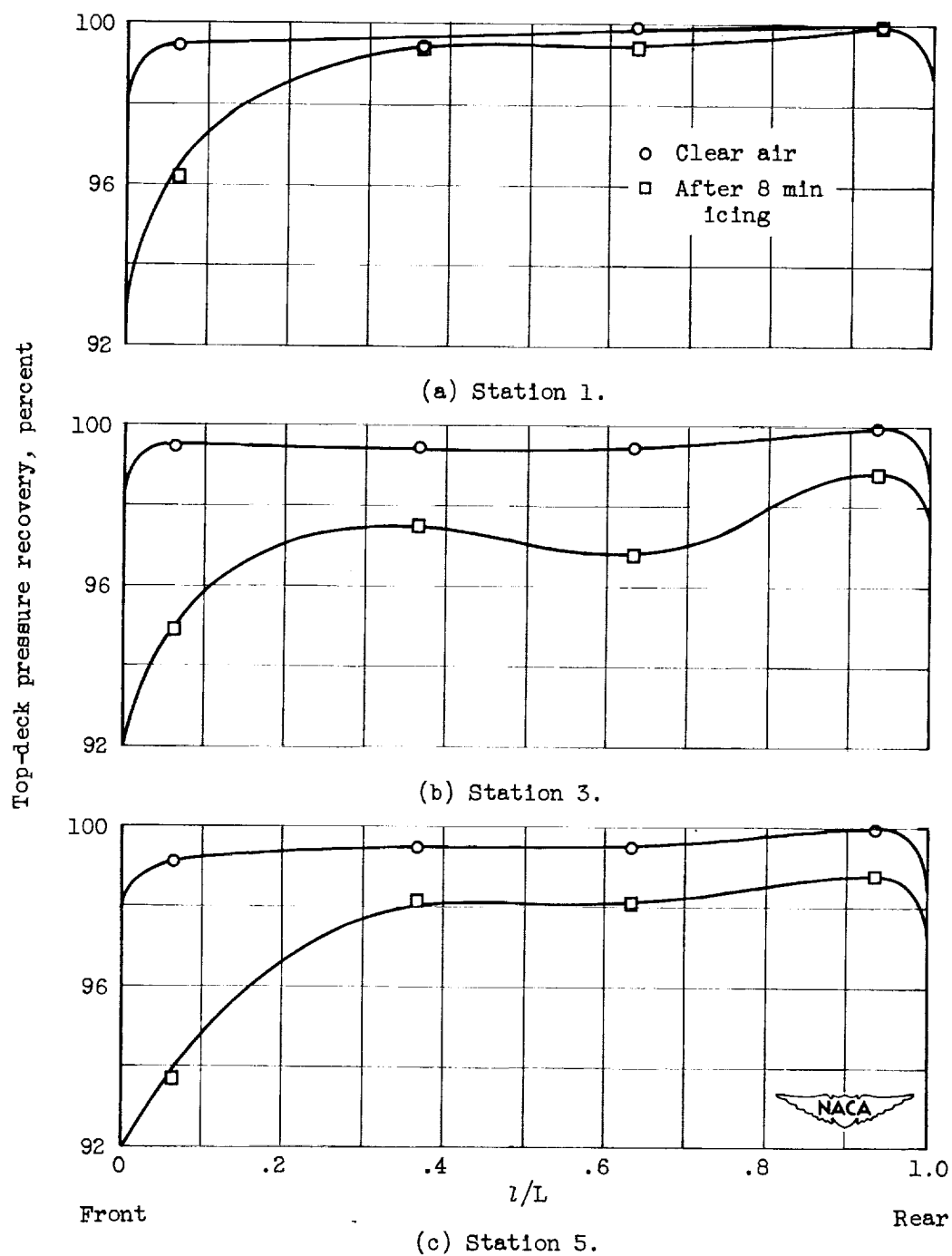


Figure 7. - Local top-deck pressure recovery in clear air and after 8 minutes icing with ram inlet only. Airspeed, 180 miles per hour; tunnel-air total temperature, 23° F; angle of attack, 0°; liquid-water content, 0.5 gram per cubic meter; median droplet diameter, 10 microns; ram-inlet mass-air-flow ratio, 0.35.

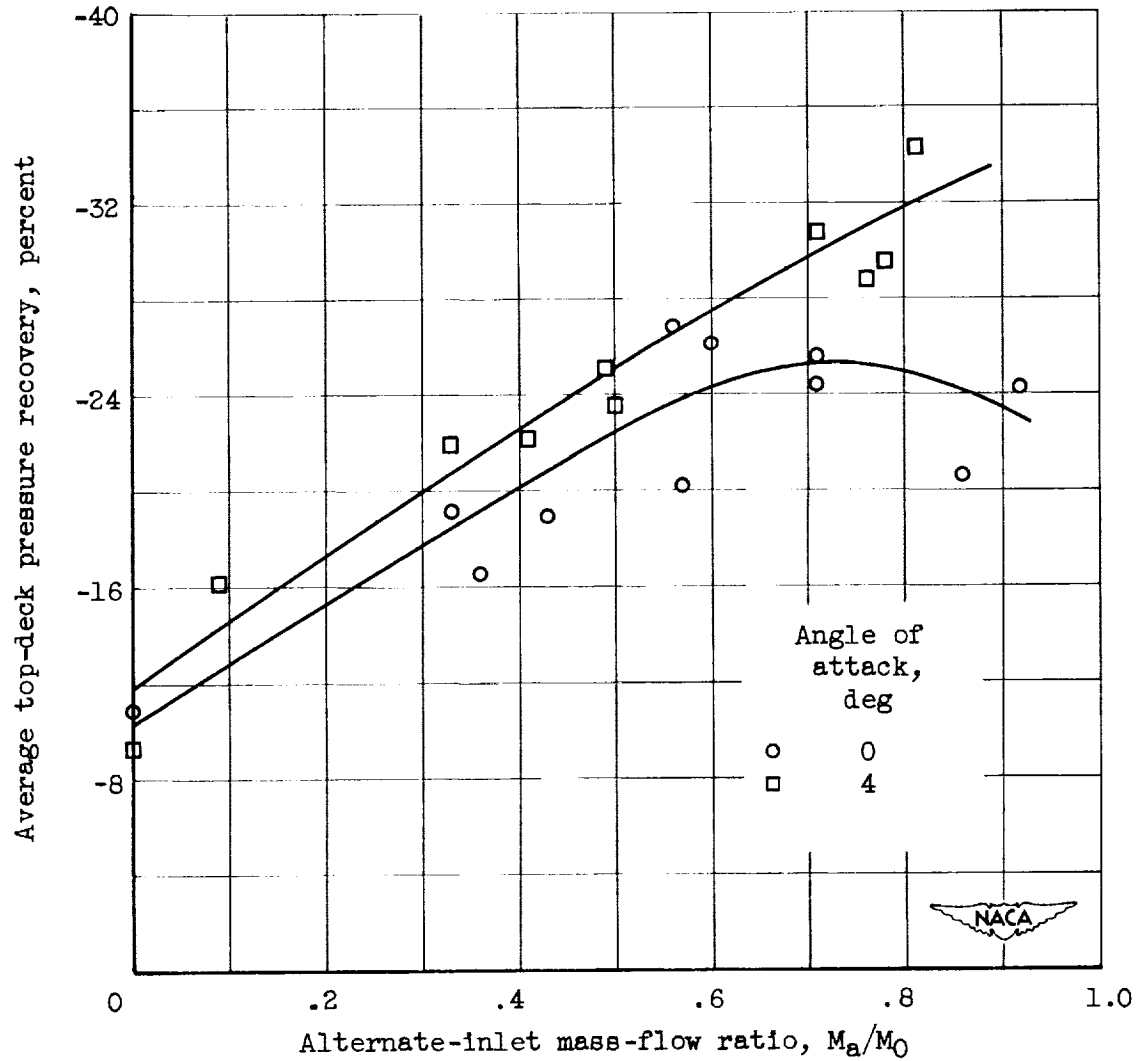
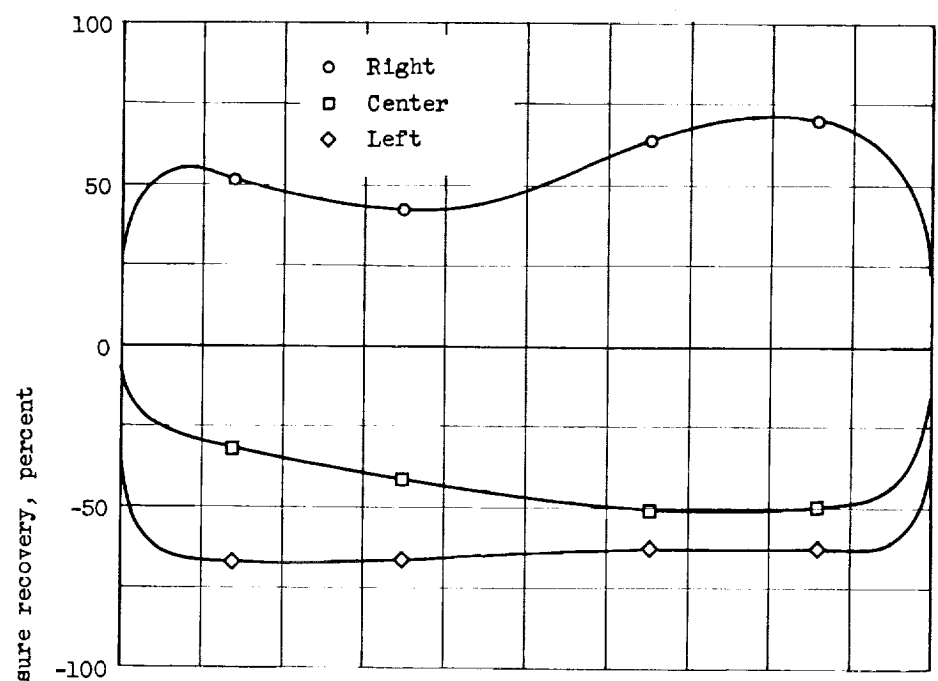
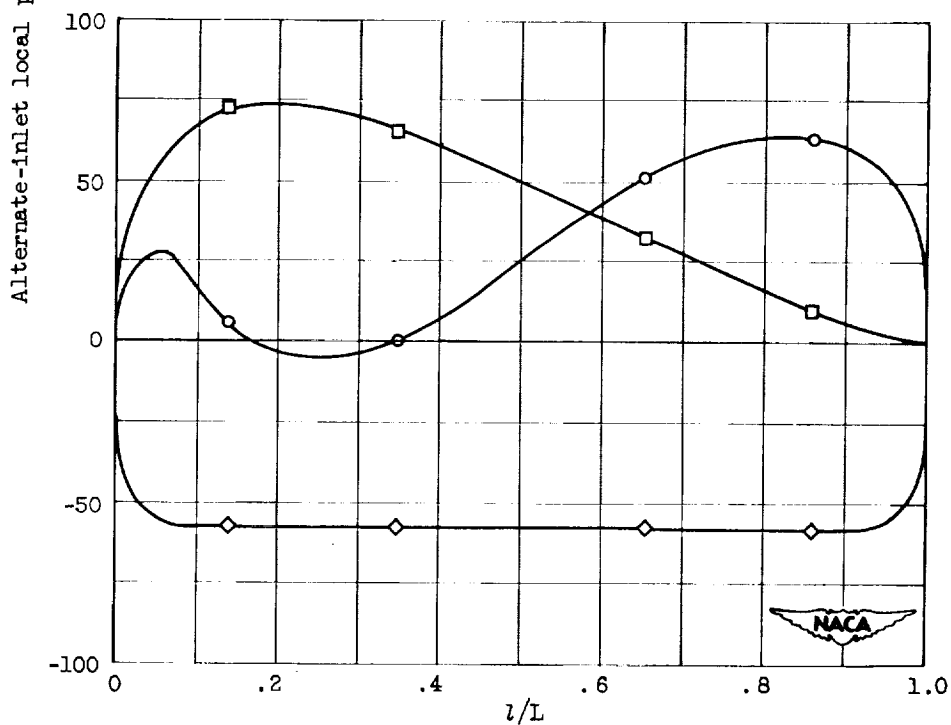


Figure 8. - Variation of average top-deck pressure recovery with alternate-inlet mass-flow ratio at two angles of attack in clear air. Tunnel-air total temperature, 25° F; airspeed, 150 to 270 miles per hour.

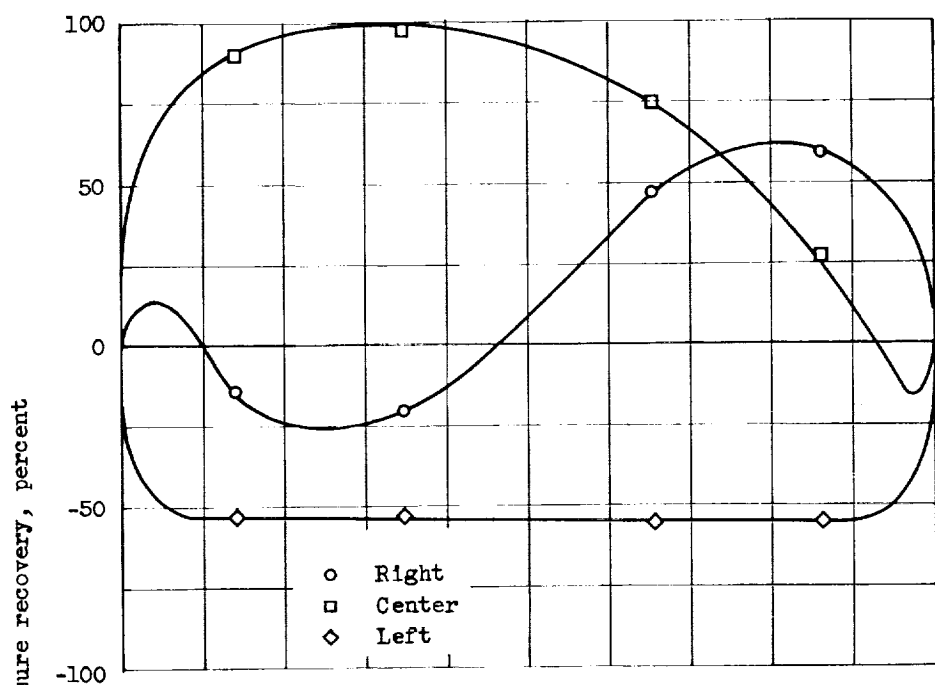


(a) Alternate-inlet mass flow, 0.



Top (b) Alternate-inlet mass flow, 2.1 pounds per second. Bottom

Figure 9. - Local pressure recovery at alternate inlet in clear air for various mass flows. Angle of attack, 0° ; airspeed, 150 miles per hour.



(c) Alternate-inlet mass flow, 2.9 pounds per second.

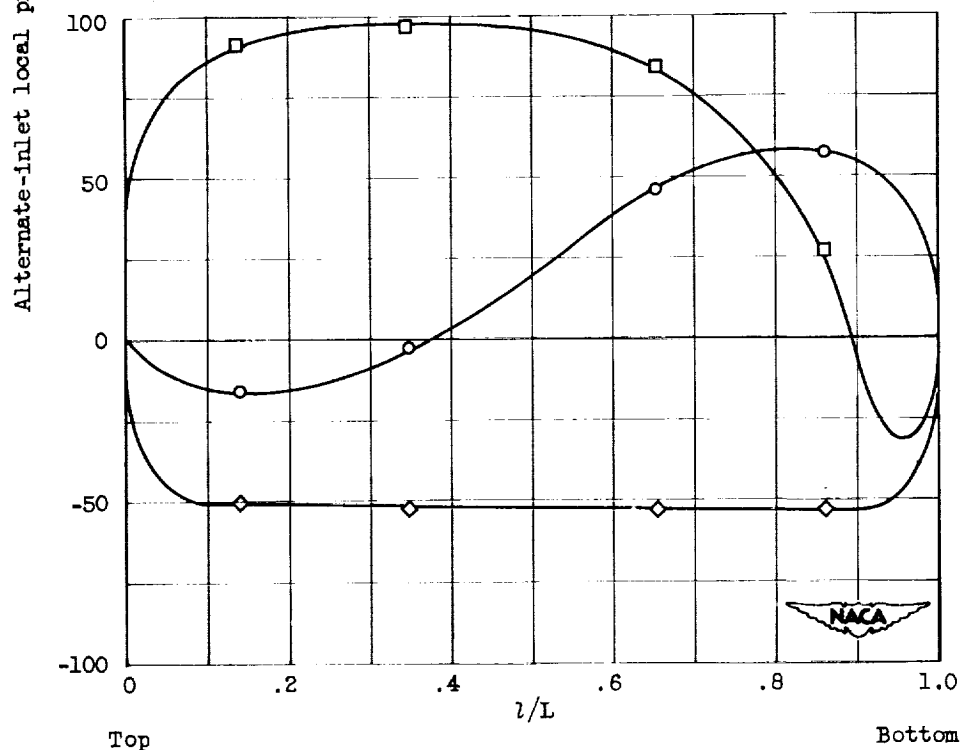
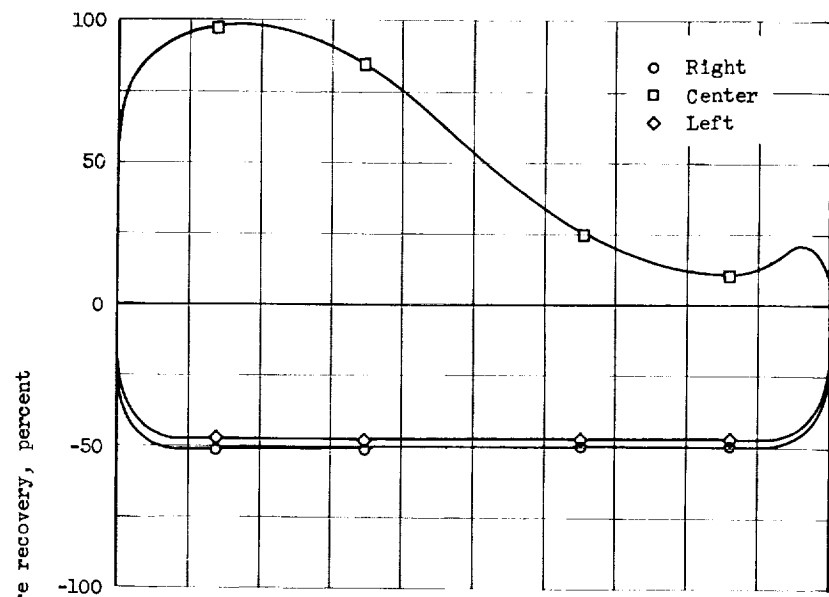


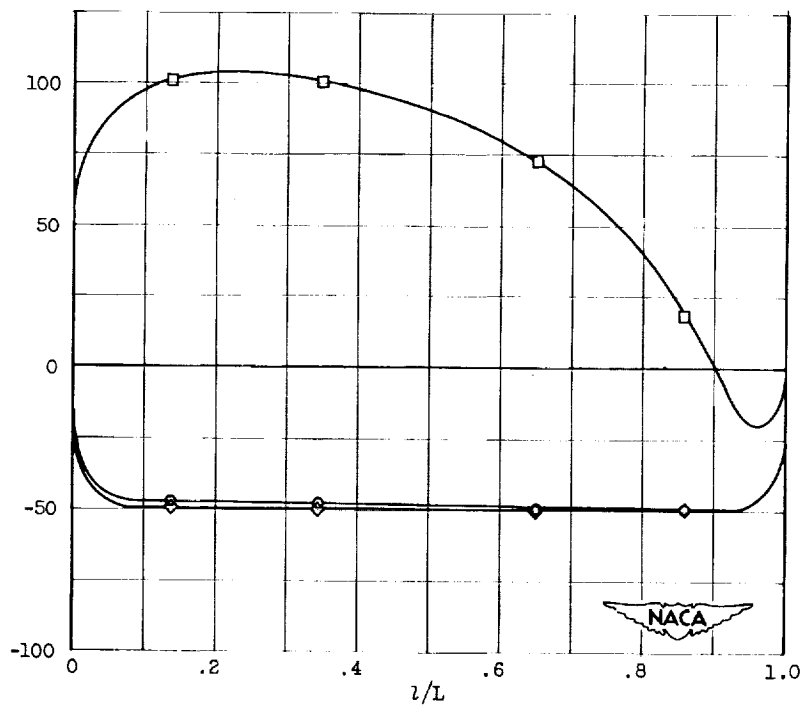
Figure 9. - Concluded. Local pressure recovery at alternate inlet in clear air for various mass flows. Angle of attack, 0° ; airspeed, 150 miles per hour.

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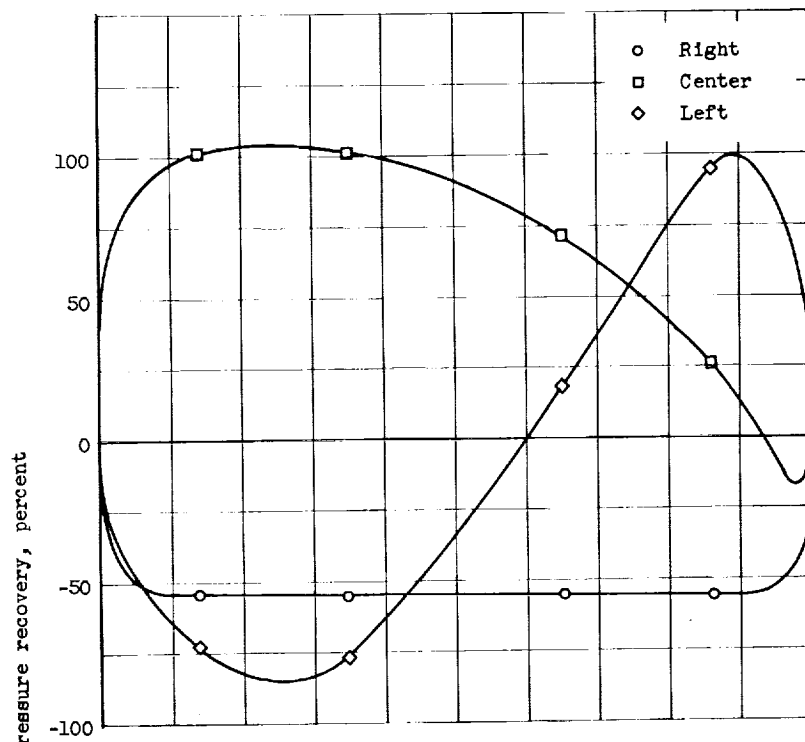


(a) Alternate-inlet mass flow, 0.

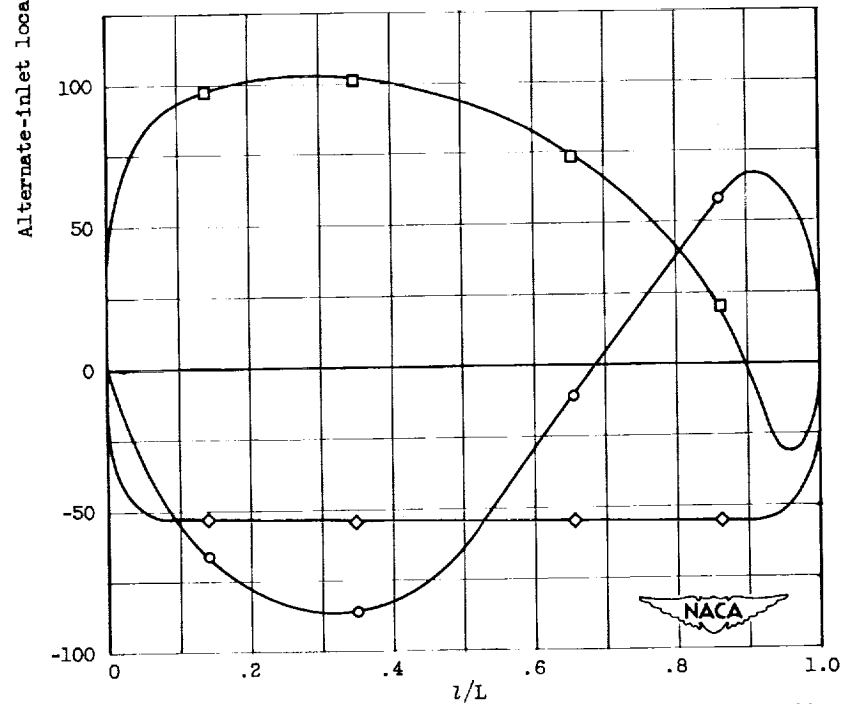


(b) Alternate-inlet mass flow, 2.1 pounds per second.

Figure 10. - Local pressure recovery at alternate inlet in clear air for various mass flows. Angle of attack, 4° ; airspeed, 150 miles per hour.



(c) Alternate-inlet mass flow, 2.9 pounds per second.



(d) Alternate-inlet mass flow, 3.1 pounds per second.

Figure 10. - Concluded. Local pressure recovery at alternate inlet in clear air for various mass flows. Angle of attack, 4° ; airspeed, 150 miles per hour.

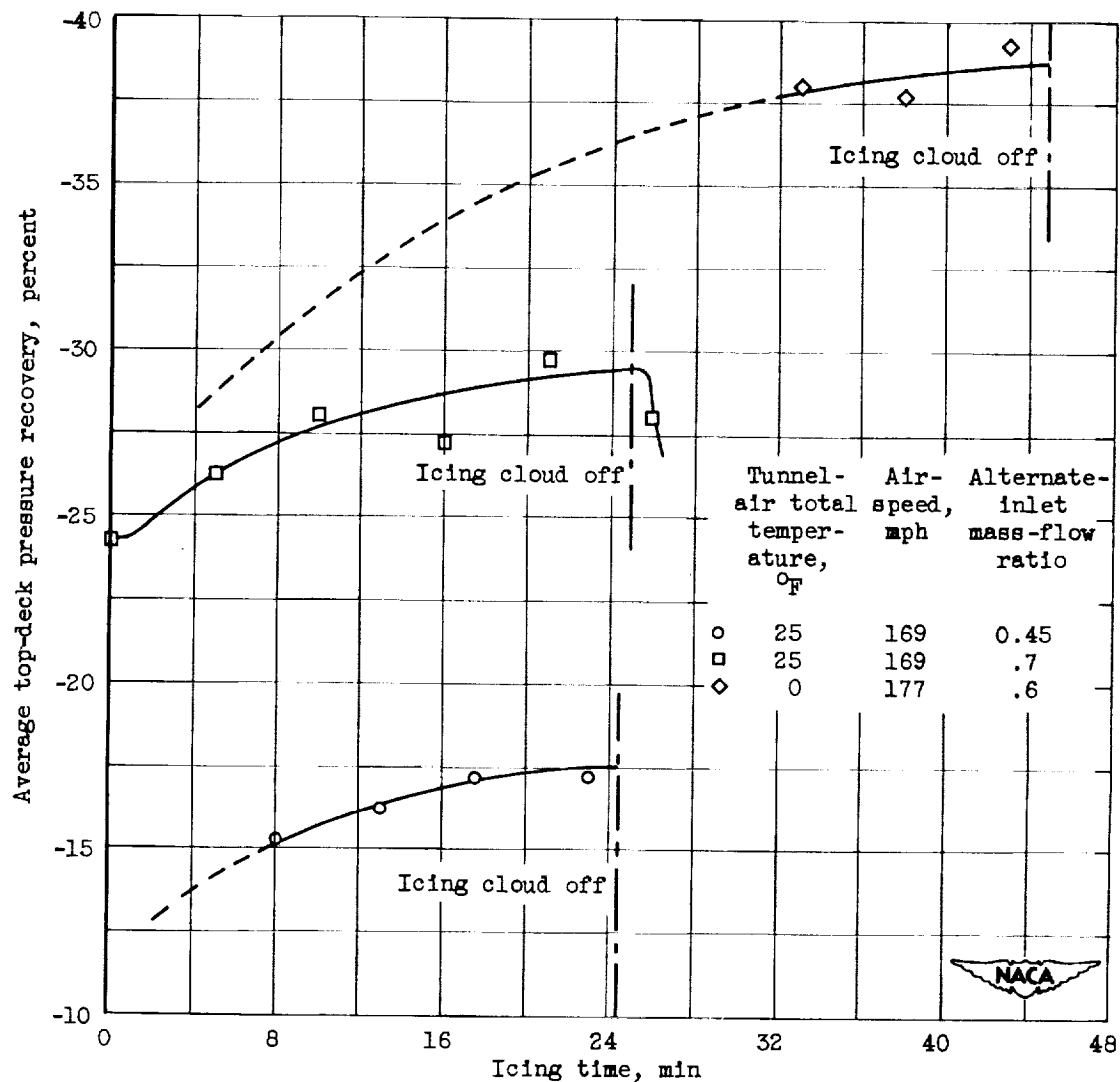
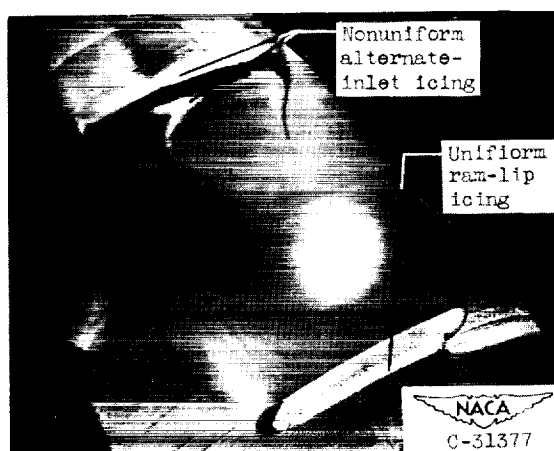
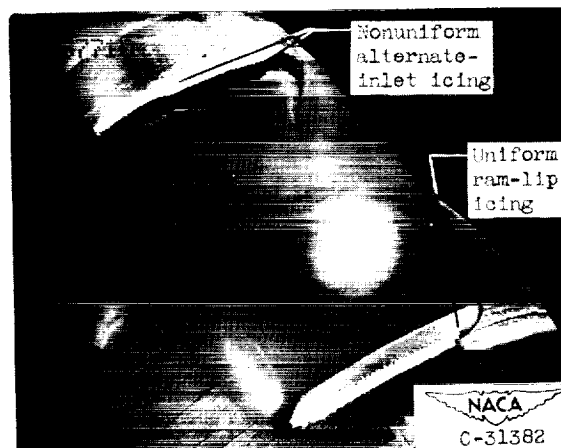


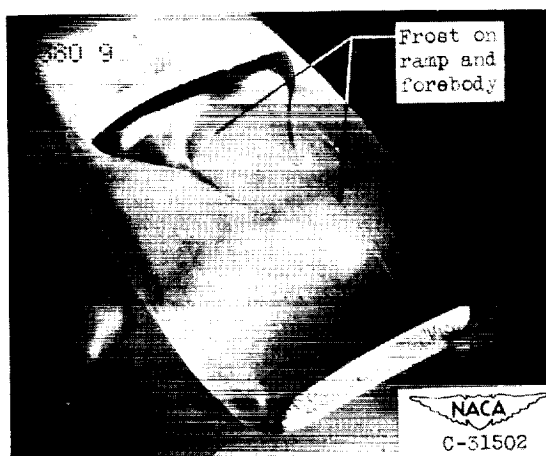
Figure 11. - Variation of average top-deck pressure recovery with icing time for alternate inlet at various air temperatures and mass-flow ratios. Angle of attack, 0° ; liquid-water content, 0.5 gram per cubic meter; median droplet diameter, 9.5 microns; ram-inlet mass-flow ratio, 0.



(a) Ice formed after 24.5 minutes of icing. Tunnel-air total temperature, 25°F ; mass-flow ratio, 0.45.



(b) Ice formed after 25 minutes of icing. Tunnel-air total temperature, 25°F ; mass-flow ratio, 0.7.



(c) Ice formed after 23 minutes of icing. Tunnel-air total temperature, 0°F ; mass-flow ratio, 0.6.

Figure 12. - Ice formed at alternate inlet at various tunnel-air temperatures and alternate-inlet mass-flow ratios. Angle of attack, 0° ; liquid-water content, 0.5 gram per cubic meter; median droplet diameter, 9.5 microns.

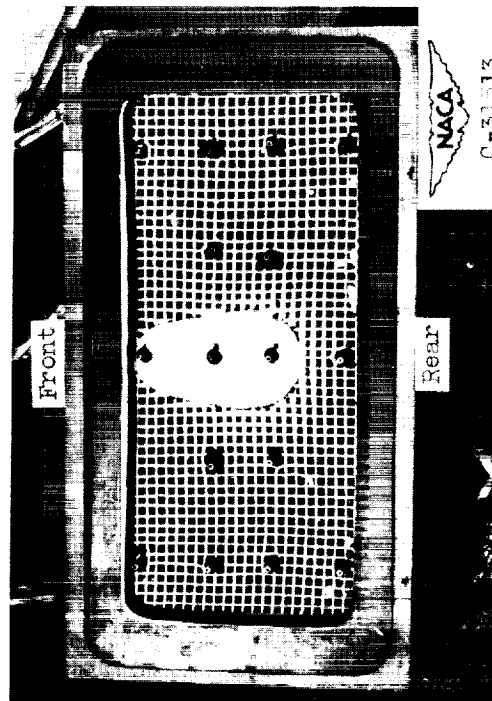
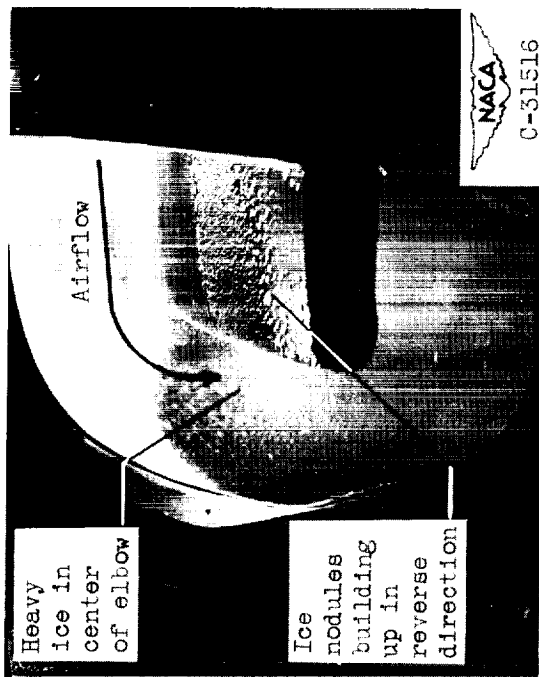


Figure 13. - Ice formed at alternate inlet after 45 minutes of icing. Liquid-water content, 0.5 gram per cubic meter; median droplet diameter, 9.5 microns; tunnel-air total temperature, 0° F; angle of attack, 0°; mass-flow ratio, 0.6.

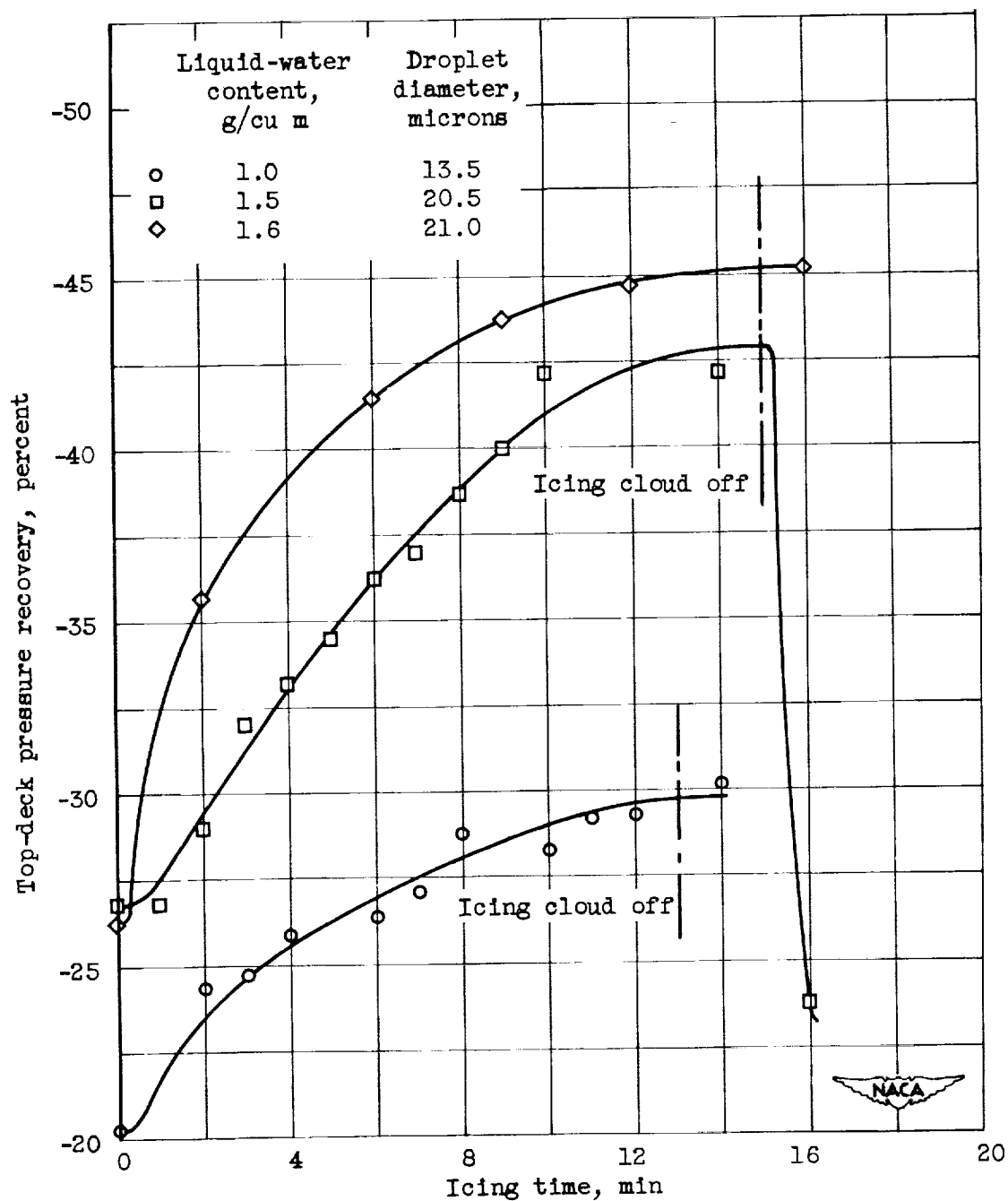


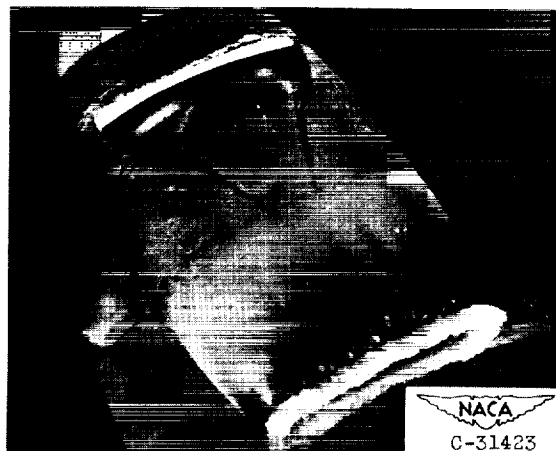
Figure 14. - Variation of top-deck pressure recovery with icing time for alternate inlet at various liquid-water contents and median droplet diameters. Airspeed, 180 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°; alternate-inlet mass-flow ratio, 0.6; ram-inlet mass-flow ratio, 0.



(a) Liquid-water content, 1.0 gram per cubic meter; median droplet diameter, 13.5 microns; icing time, 13 minutes.



(b) Liquid-water content, 1.5 grams per cubic meter; median droplet diameter, 20.5 microns; icing time, 15 minutes.



(c) Liquid-water content, 1.6 grams per cubic meter; median droplet diameter, 21 microns; icing time, 15 minutes.

Figure 15. - Ice formed at alternate inlet at various icing conditions. Airspeed, 180 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°; alternate-inlet mass-flow ratio, 0.6.

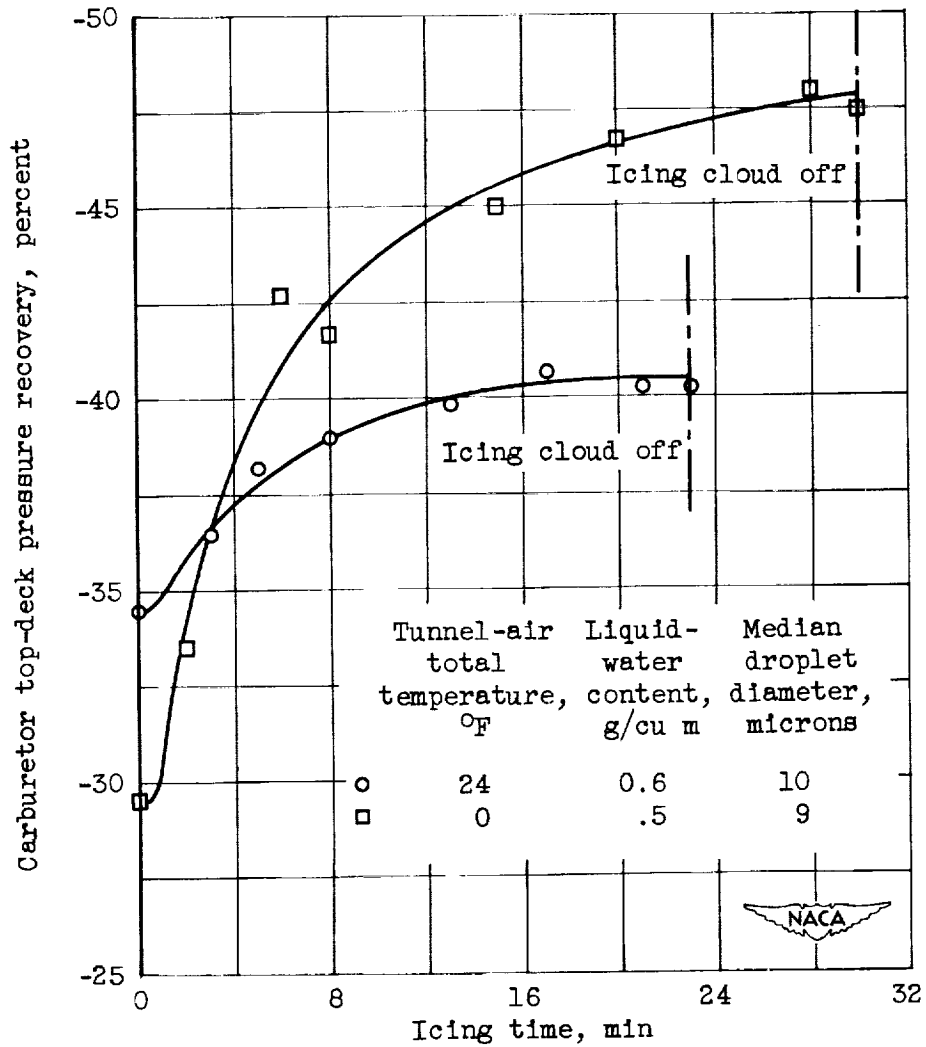


Figure 16. Variation of top-deck pressure recovery of alternate inlet with icing time at two tunnel-air total temperatures. Airspeed, 150 miles per hour; angle of attack, 4° ; alternate-inlet mass-flow ratio, 0.8; ram-inlet mass-flow ratio, 0.

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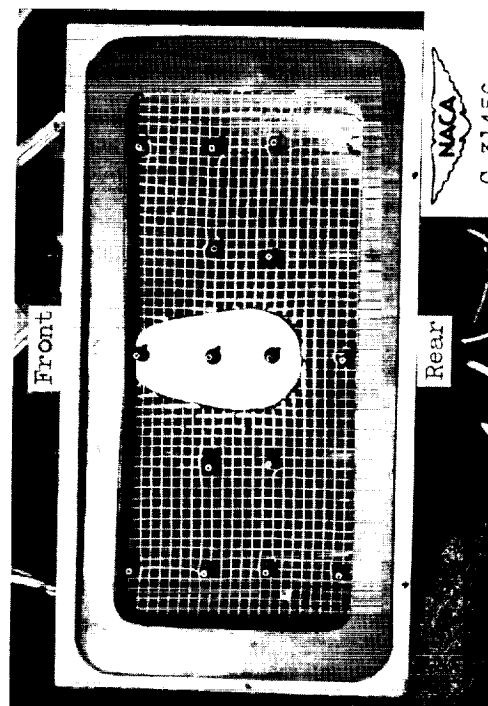
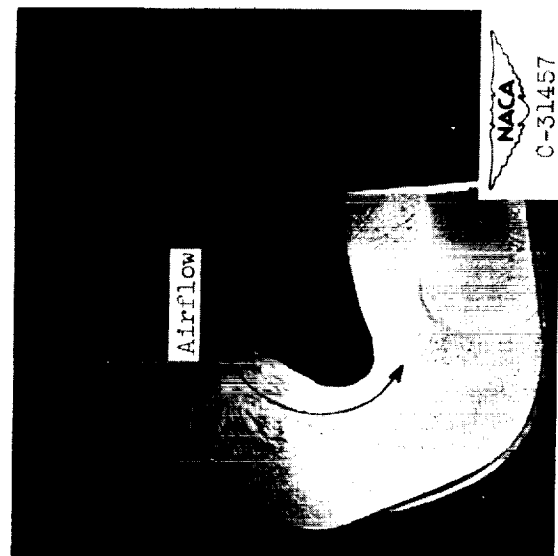


Figure 17. - Ice formed at alternate inlet after 23 minutes. Airspeed, 150 miles per hour; tunnel-air total temperature, 24°F ; angle of attack, 4° ; liquid-water content, 0.6 gram per cubic meter; median droplet diameter, 10 microns; mass-air-flow ratio, 0.8.

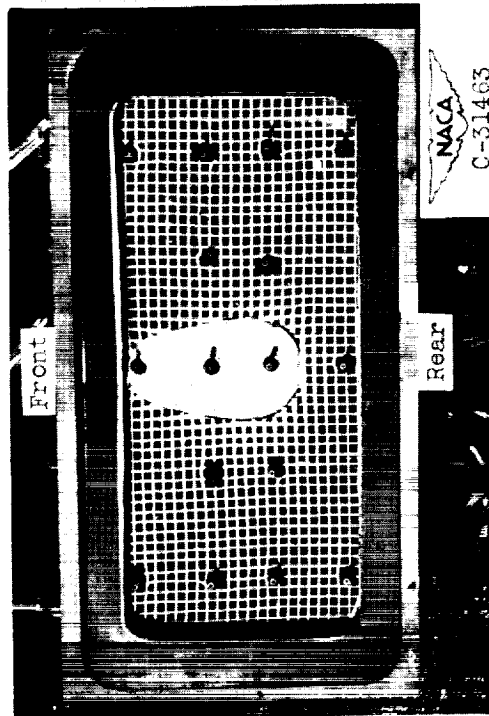


Figure 18. - Ice formed at alternate inlet after 30 minutes. Airspeed, 150 miles per hour; tunnel-air total temperature, 0° F; angle of attack, 4° ; liquid-water content, 0.5 gram per cubic meter; median droplet diameter, 9 microns; mass-air-flow ratio, 0.8.

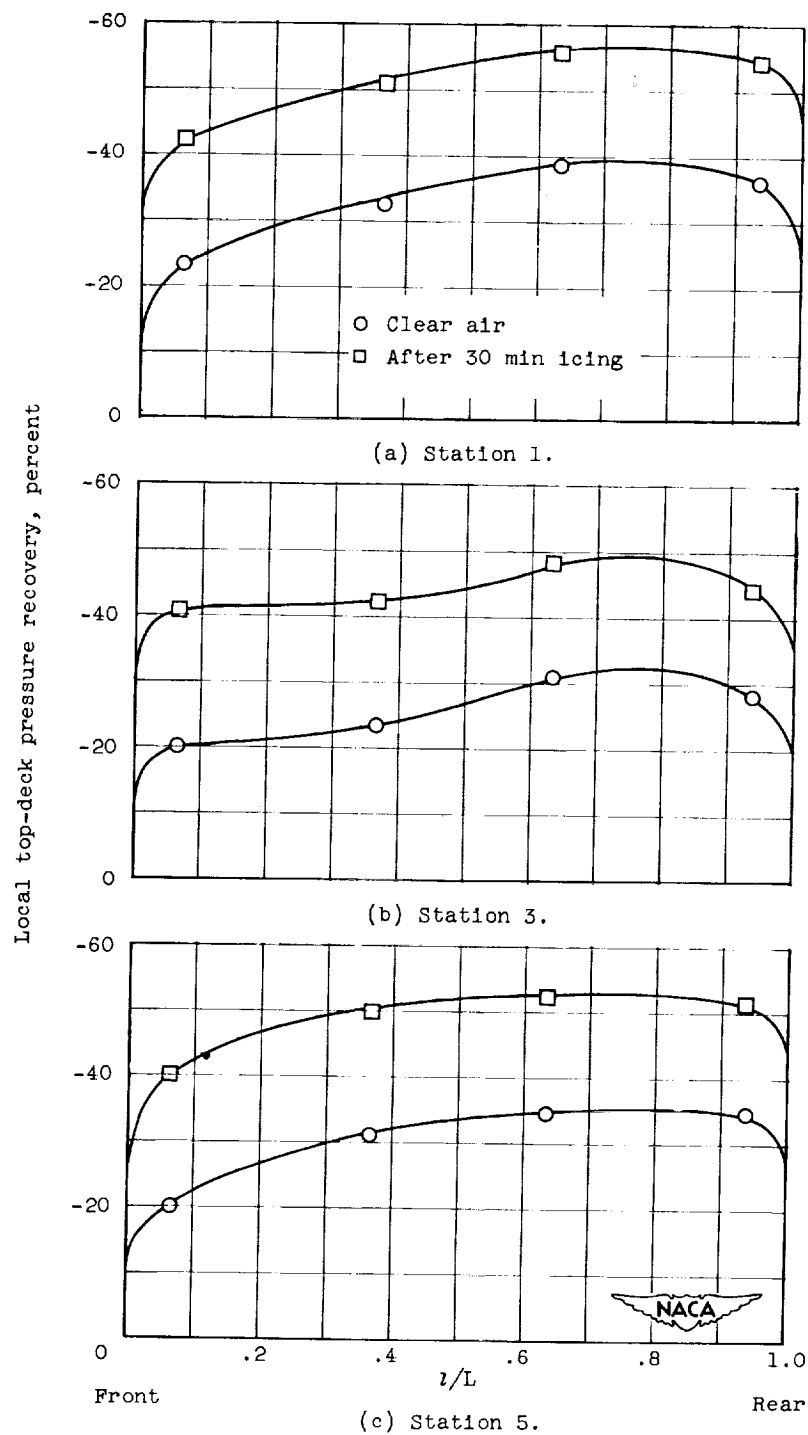


Figure 19. - Local top-deck pressure recovery in clear air and after 30 minutes icing with alternate inlet. No ram; airspeed, 150 miles per hour; tunnel-air total temperature, 0° F; angle of attack, 4°; liquid-water content, 0.5 gram per cubic meter; median droplet diameter, 9 microns; alternate-inlet mass-flow ratio, 0.8.

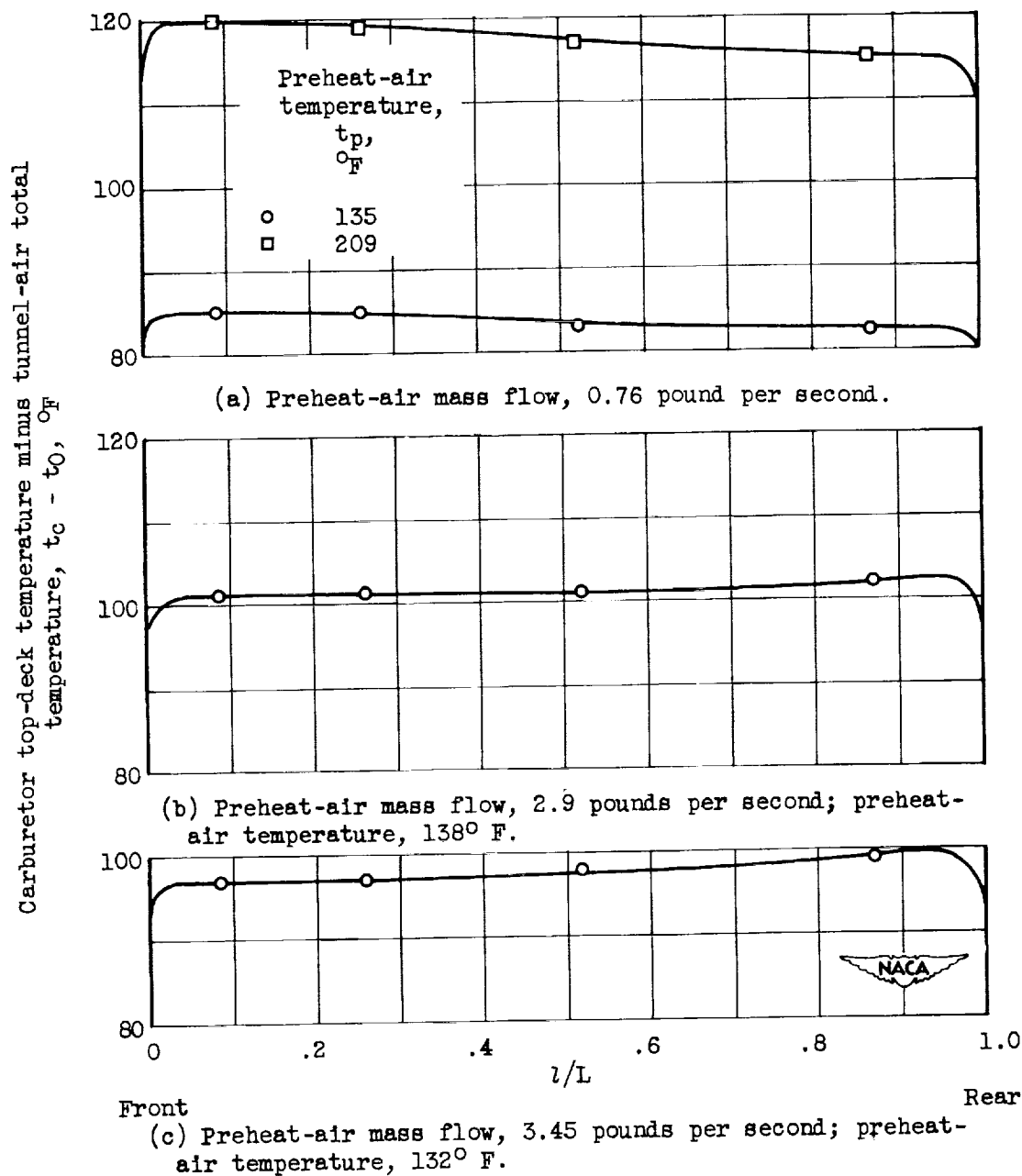
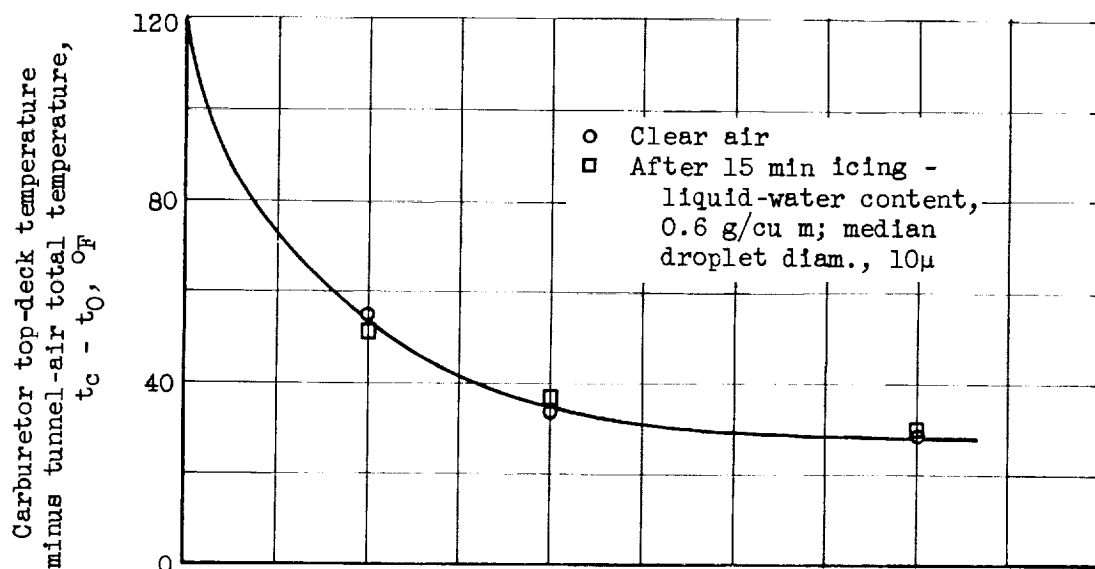
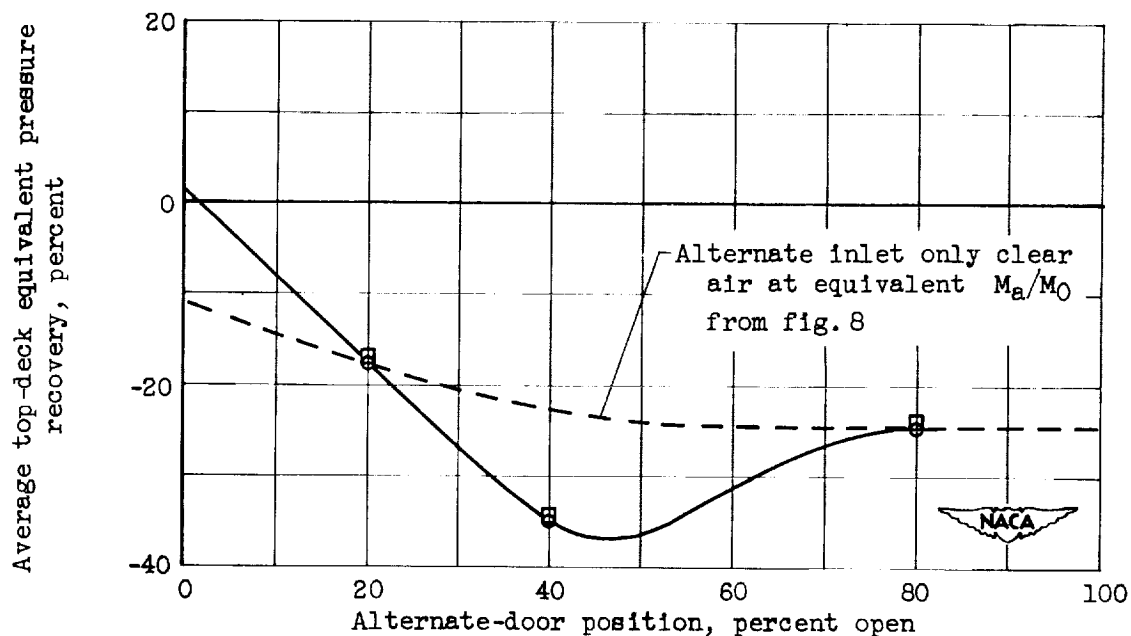


Figure 20. - Distribution of top-deck air temperature for various preheat-air flows with preheat door fully open and alternate door closed. Airspeed, 200 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°.



(a) Average top-deck temperature.



(b) Average top-deck equivalent pressure recovery.

Figure 21. - Variation of top-deck temperature and pressure recovery with alternate-door position. Preheat door fully open; no ram; airspeed, 150 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°; preheat-air mass flow, 0.77 pound per second; preheat-air average inlet temperature, 212° F.

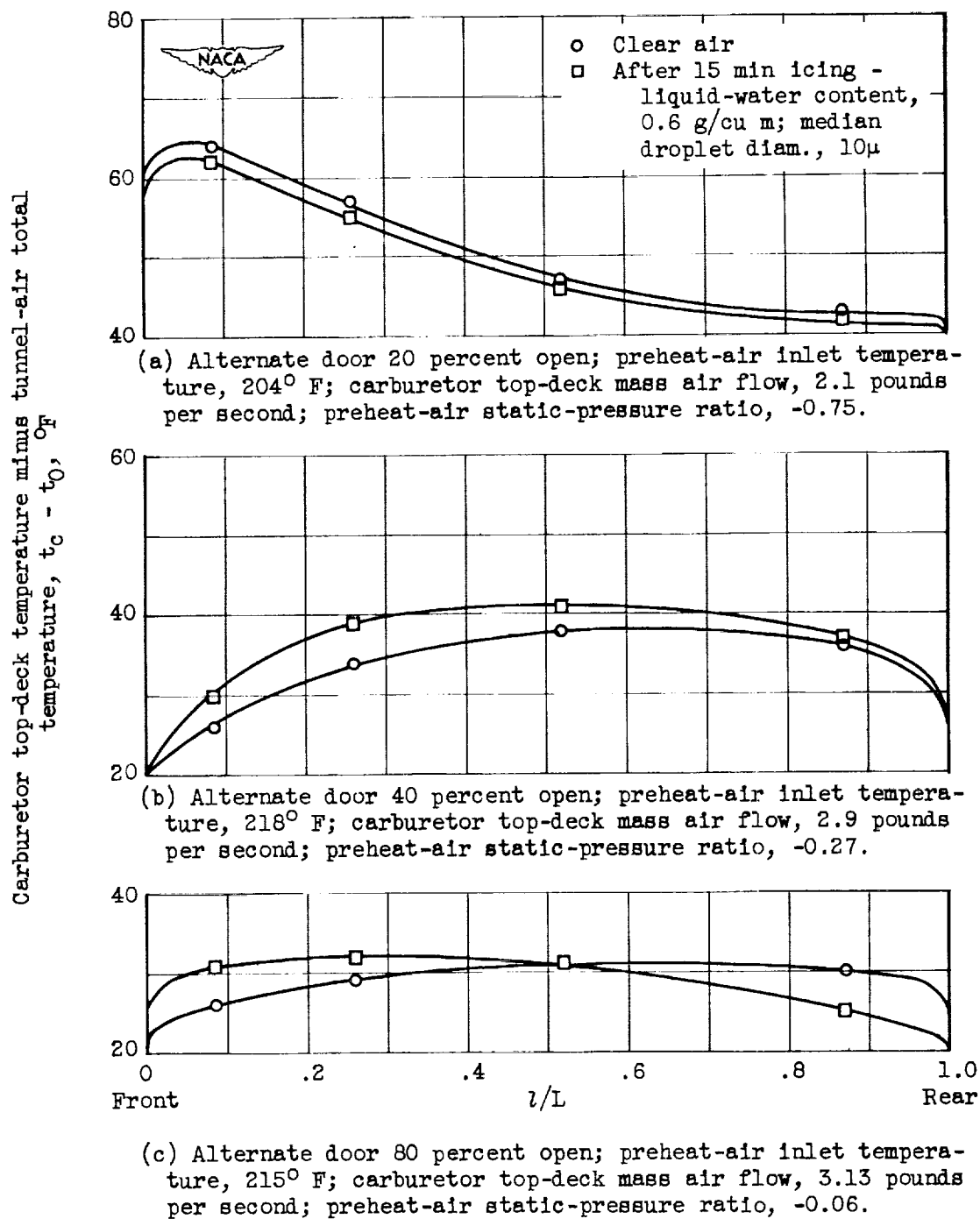
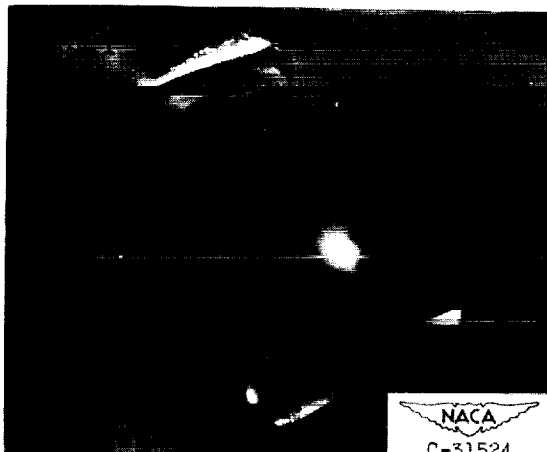
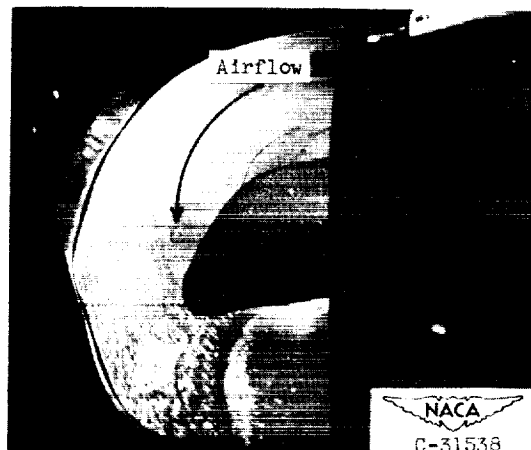
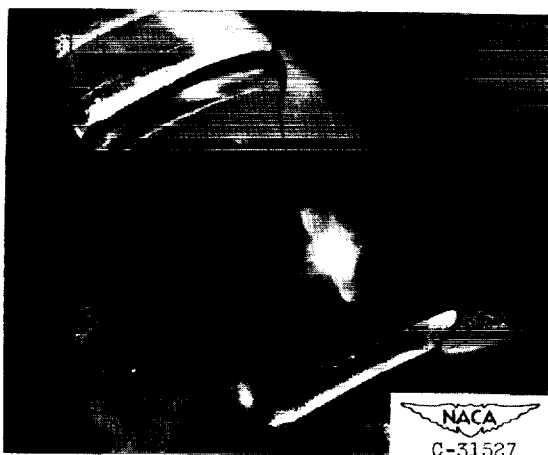


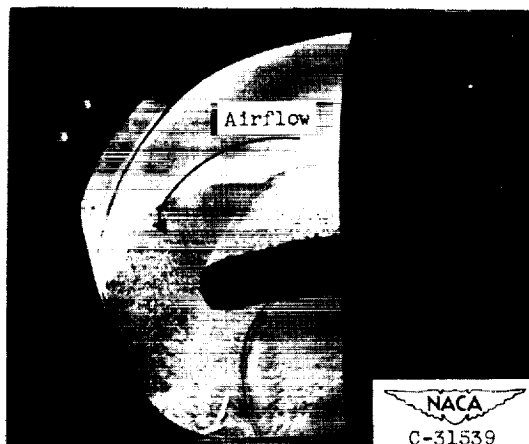
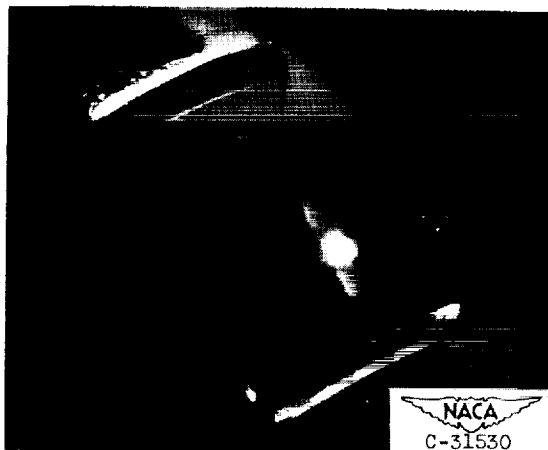
Figure 22. - Distribution of carburetor top-deck air temperature for various alternate-door positions. Preheat door fully open; no ram; airspeed, 150 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°; preheat-air flow, 0.77 pound per second.



(a) Alternate door 20 percent open; preheat-air inlet temperature, 204°F ; carburetor top-deck mass air flow, 2.1 pounds per second.



(b) Alternate door 40 percent open; preheat-air inlet temperature, 218°F ; carburetor top-deck mass air flow, 2.9 pounds per second.



(c) Alternate door 80 percent open; preheat-air inlet temperature, 215°F ; carburetor top-deck mass air flow, 3.13 pounds per second.

Figure 23. - Ice formations on scoop and alternate-duct elbow after 15 minutes icing with preheat door open and alternate door in various positions. Airspeed, 150 miles per hour; tunnel-air total temperature, 25°F ; angle of attack, 0° ; preheat-air mass flow, 0.77 pound per second; liquid-water content, 0.6 gram per cubic meter; median droplet diameter, 10 microns.

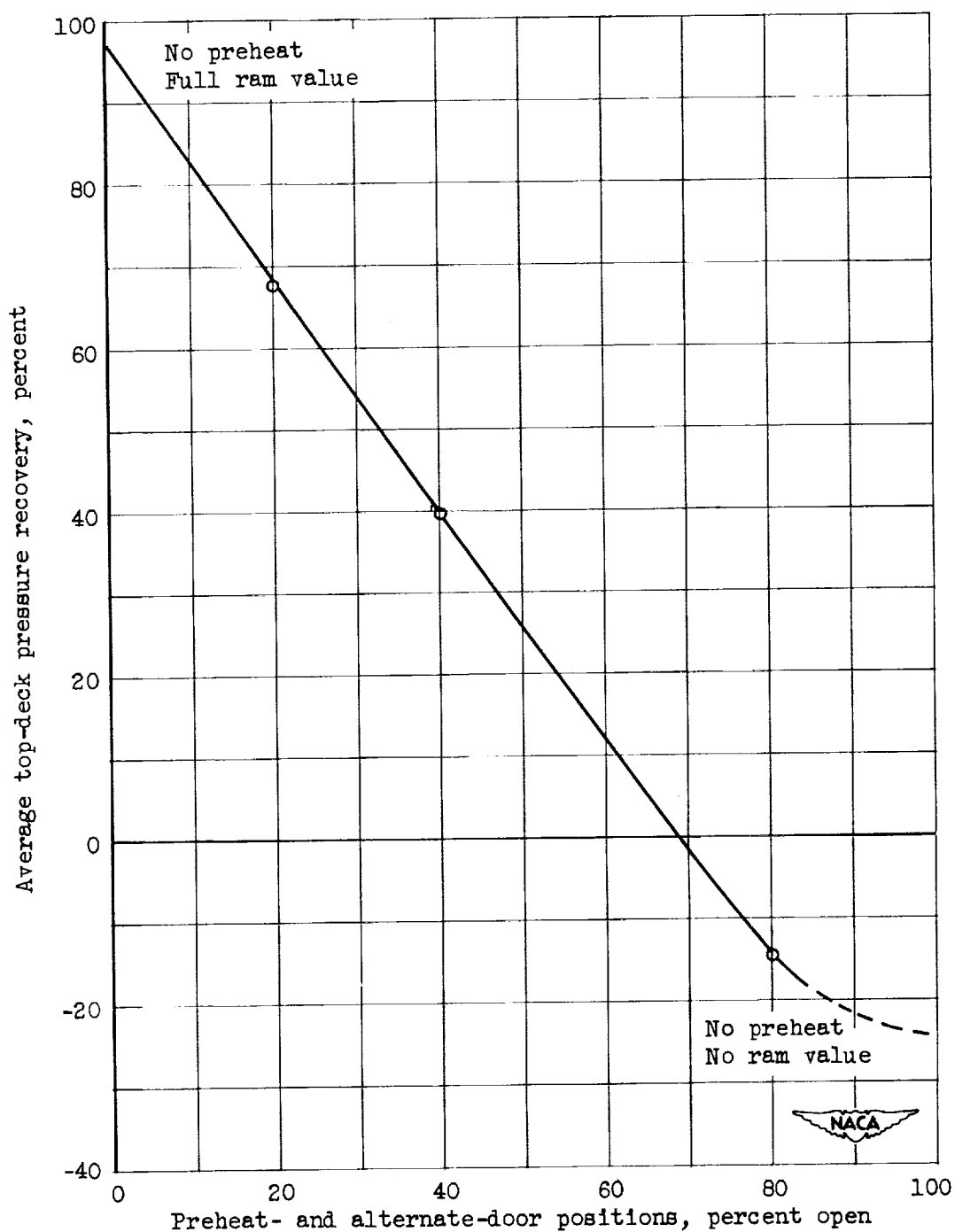


Figure 24. - Variation of average top-deck pressure recovery with preheat- and alternate-door positions. Airspeed, 150 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°; preheat mass air flow, 0.57 pound per second; carburetor top-deck mass air flow, 3.24 pounds per second.

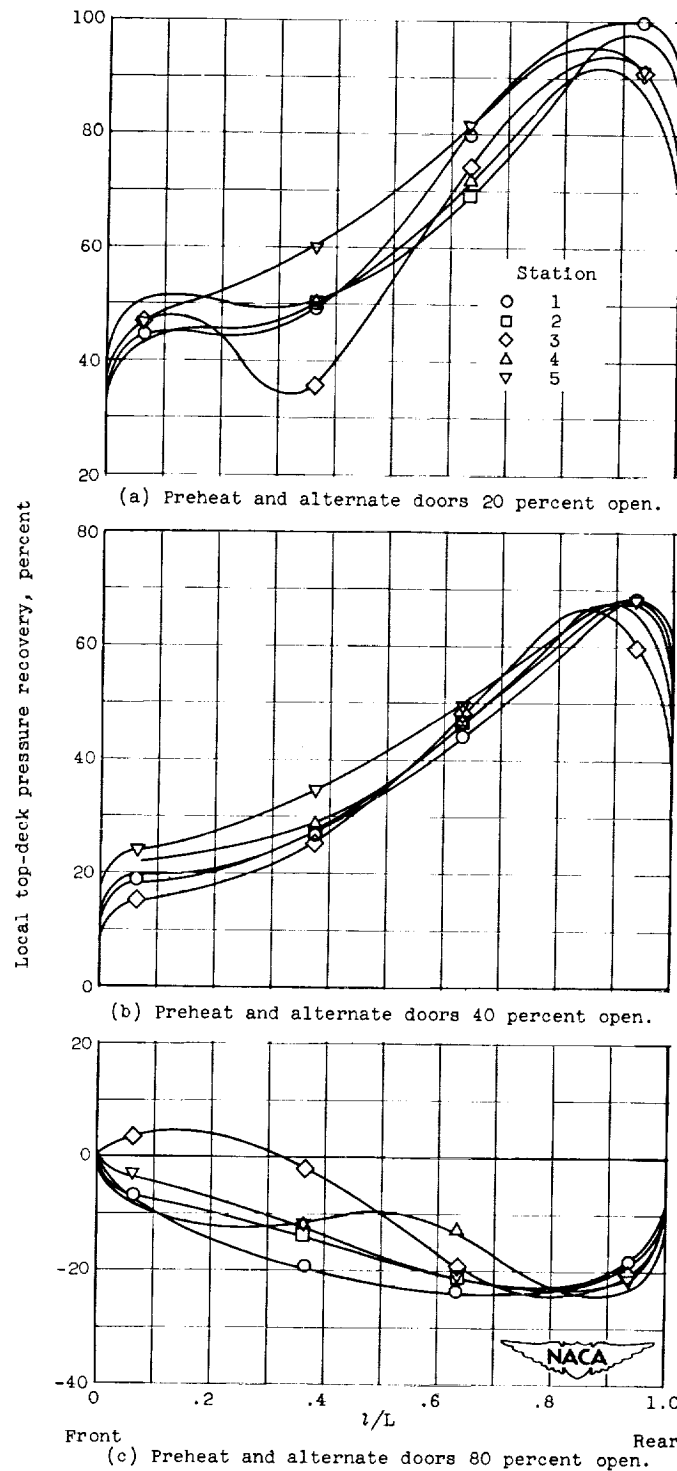


Figure 25. - Local top-deck pressure recovery for various preheat- and alternate-door positions. Airspeed, 150 miles per hour; tunnel-air total temperature, 25° F; angle of attack, 0°; preheat mass air flow, 0.57 pound per second; carburetor top-deck mass air flow, 3.24 pounds per second; preheat-air temperature, 137° F.

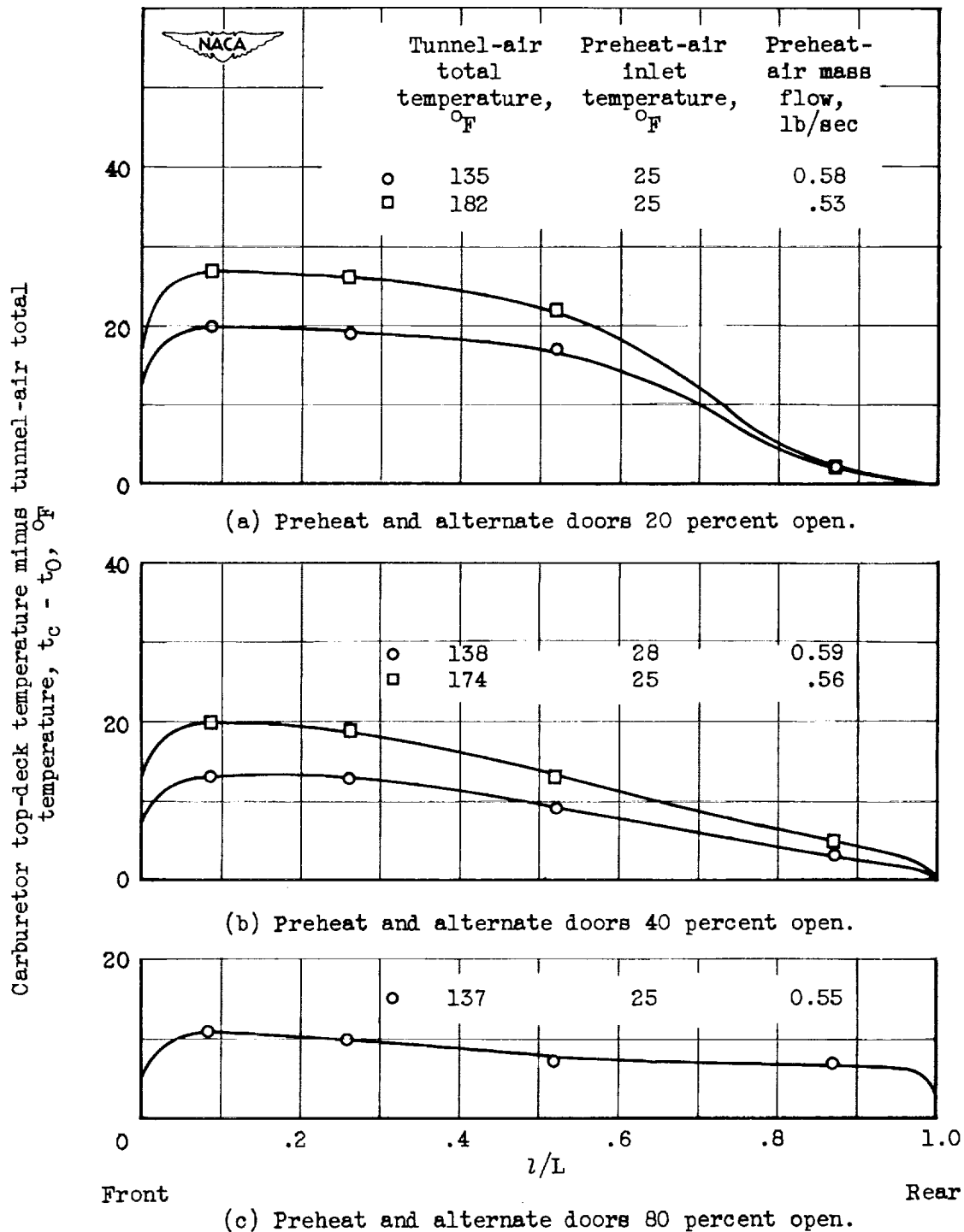


Figure 26. - Distribution of top-deck air temperatures for various preheat- and alternate-door positions. Airspeed, 150 miles per hour; angle of attack, 0° ; carburetor top-deck mass air flow, 3.24 pounds per second.